ARCHITECTURE DEPARTMENT **CHINESE UNIVERSITY OF HONG KONG**

MASTER OF ARCHITECTURE PROGRAMME 2008-2009 DESIGN REPORT

FROM COMPONENT TO FORM: EXPLORATION WITH PARAMETRIC MODELING TOOL

HAU Sum Ming Sam May 2009

From Component to Form
Exploration with Parametric Modeling Tool

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ABSTRACT
This project will explore a design process based on geometrical and structural understanding of a component and explore the form variation with structural consideration and fabrication constraint.

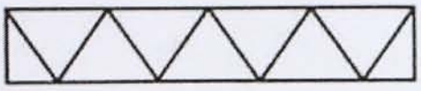
STATEMENT
In the current practice of architecture, parametric design tool is used for providing data of building components after the form finding phase. Since the form is defined independently with the components, architects have to deal with the specific configuration and more effort is needed.
This project will explore the possibility of a design process in the reversed way. The design will start with a basic geometrical and structural understanding of a component and then explore the potential of form variation within the constraint of fabrication and structural geometry. The form will be further modified with the structural analysis and spatial concept, in order to transfer it to architecture. Therefore, an architectural design which is constructible with the components and within the structure and fabrication possibility can be realized.

Design process:
The whole design process is composed by an open ended series of paths which accumulate different ideas and decisions around the same topics: What form can the components do and how does the form transfers to an architecture? Every ideas and decisions made are based on the previous stage of exploration. Therefore, the design developed is a Long chain of geometric dependency which connects different scale of design, from component to form.

PART1: GEOMETRICAL AND STRUCTURAL UNDERSTANDING OF A COMPONENT

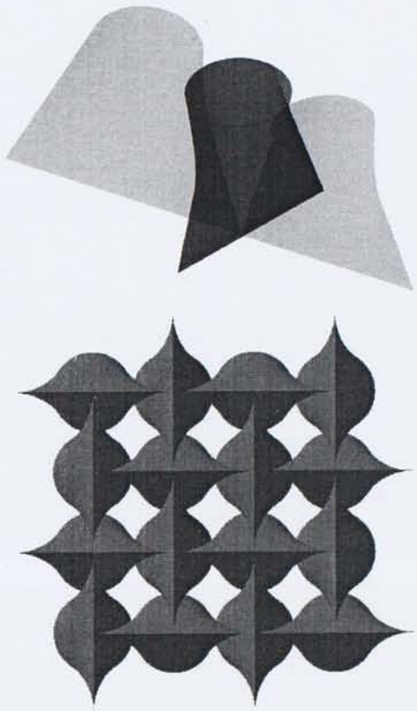
A component developed by combining the structural principle of a truss and bending surface will be used as an experimental module in this project. This part includes the fundamental understanding of geometry, like how the curves and surface defined.
The loading performance of the assembled components will be analyzed. Based on the result of the analysis, the adjustment of the components will be proposed to enhance the structure.
The geometrical and structural understanding helps to set up the fundamental constraints for the form variation in the next stage.

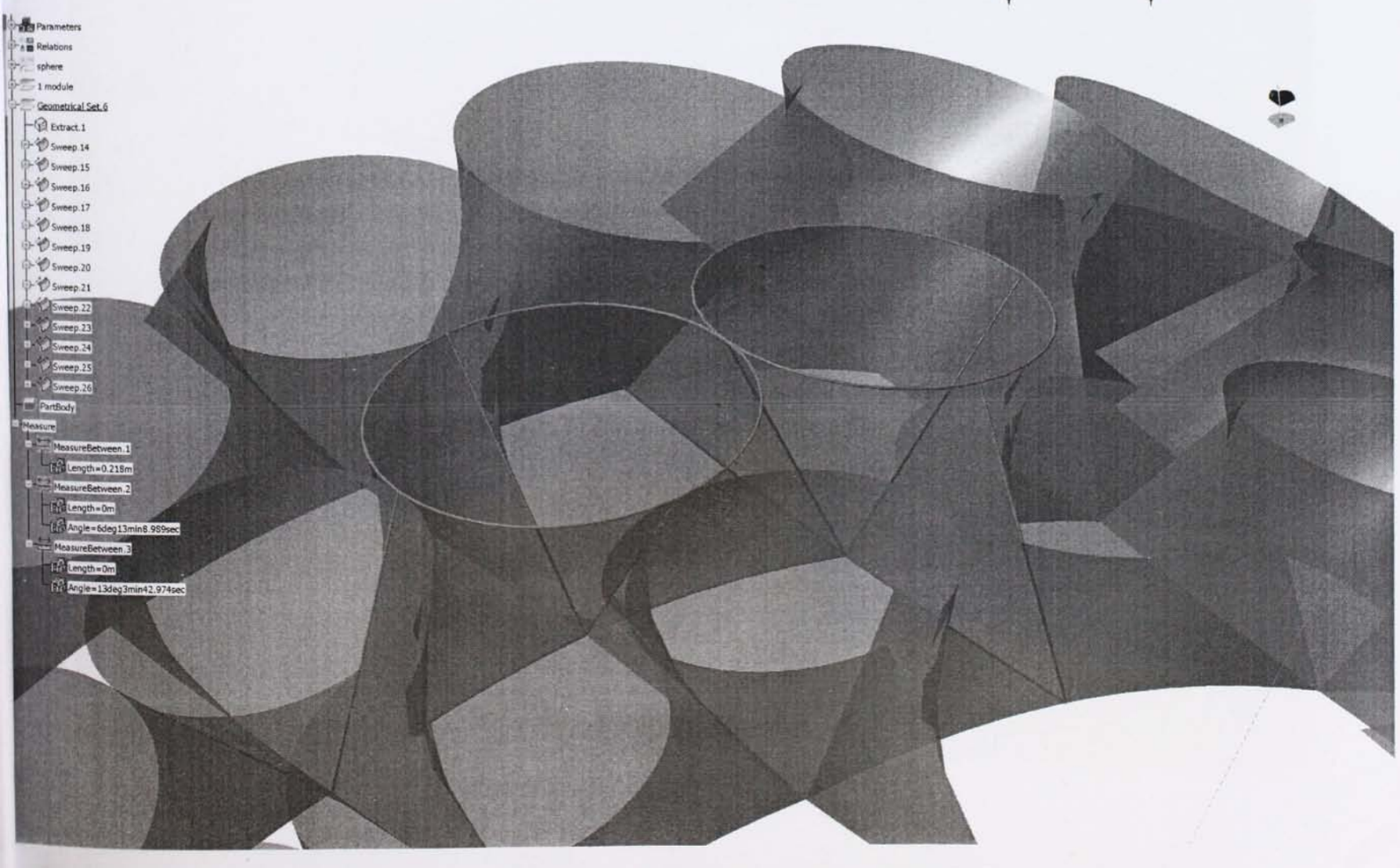
STRUCTURAL CONCEPT



The diagonal member of the truss is the critical structural element to resist the force of deformation

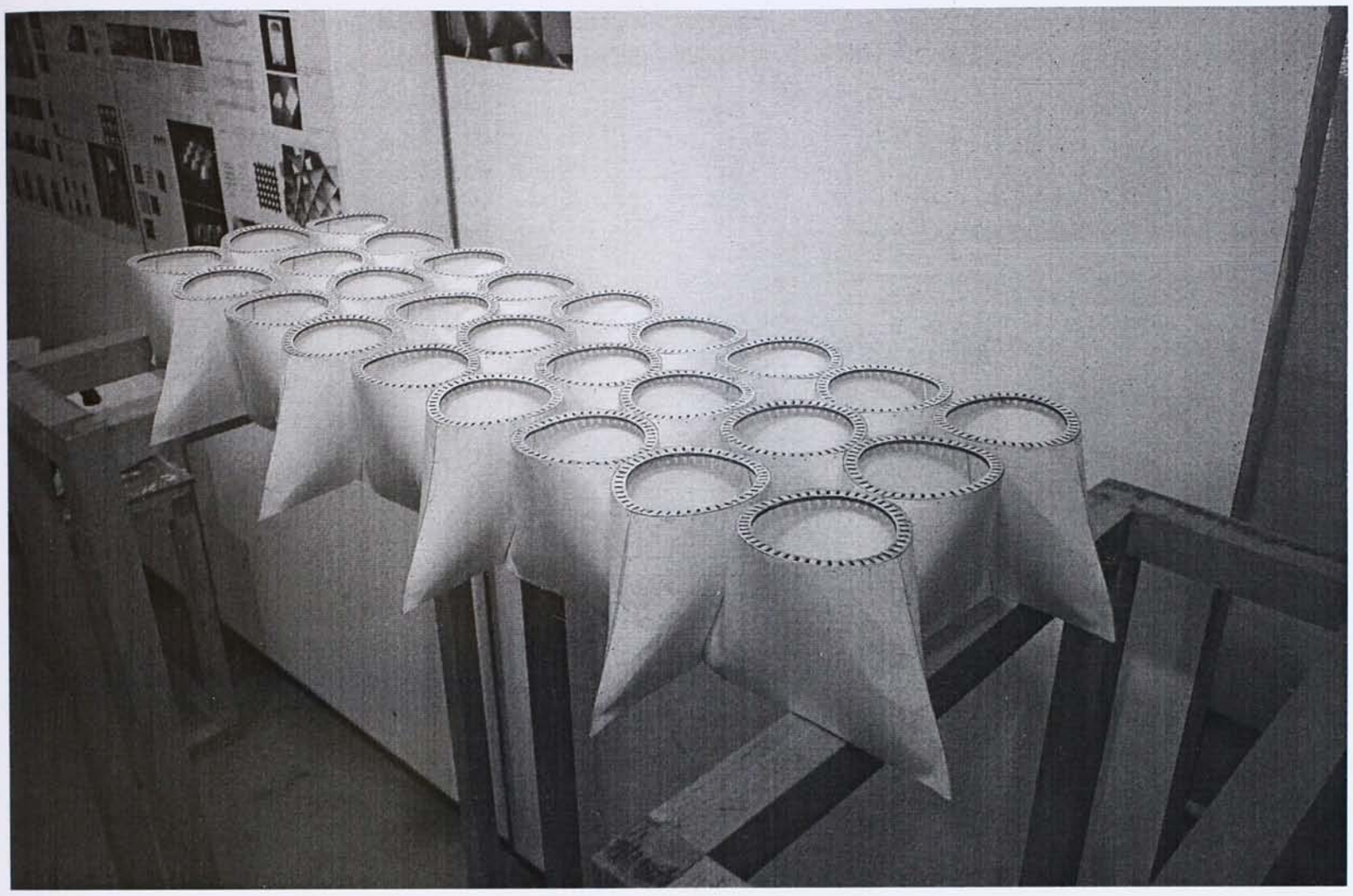
The additional strength is added to a bending sheet

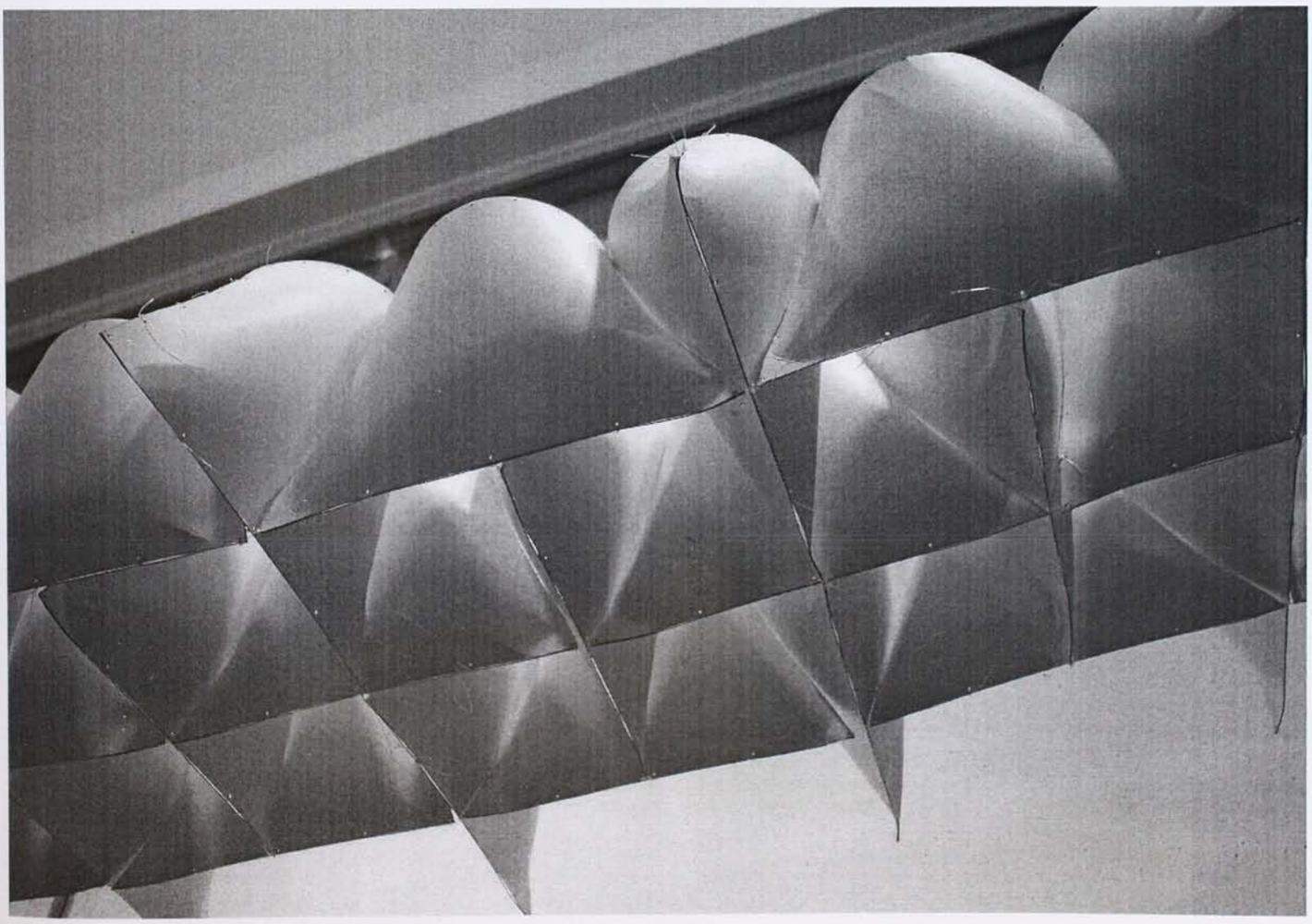




STRUCTURAL PERFORMANCE

Study model to experiment about the structural performance of the assembled components.





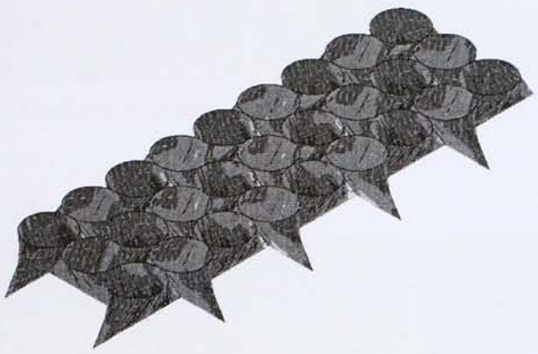
STRUCTURAL PERFORMANCE

Span: 24m
Thickness:2m

Joint condition: Fixed
Boundary condition: Pinned
Loading: Distributed Loading -1 kN/m

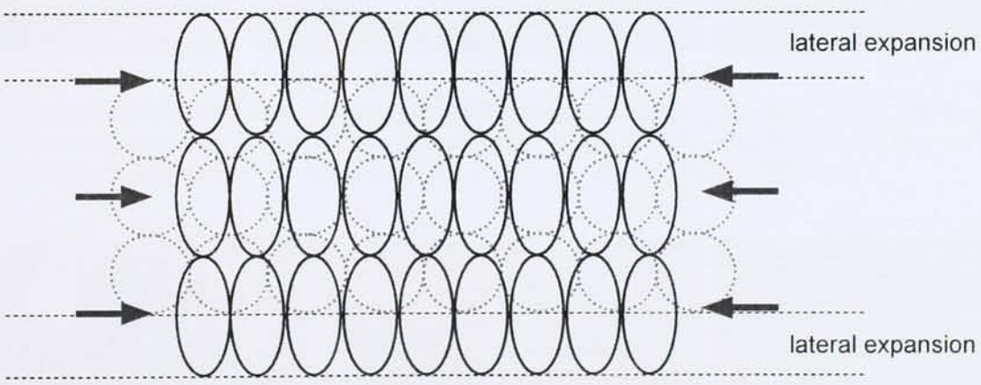
Member type: Pipe
Diameter: 20mm
Wall thickness: 2mm

Loading



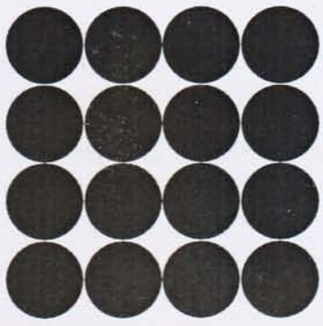
Stress diagram

Deflected shape



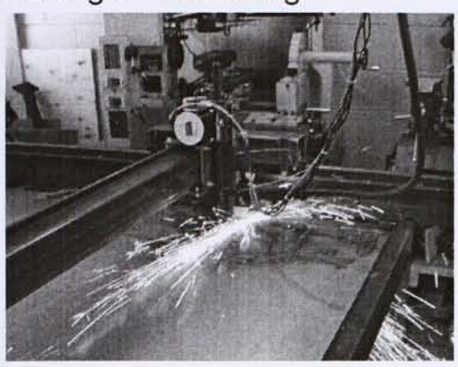
Enhancement of the structure

The analysis shows that the deformation of the ring is the major deflection factor of the whole span. Therefore, more material is needed to maintain the shape of ring. Because the bucket shape of the module have more space to occupy more material on the ring layer. Therefore, the ring is the layer for compression and the edge is for tension.

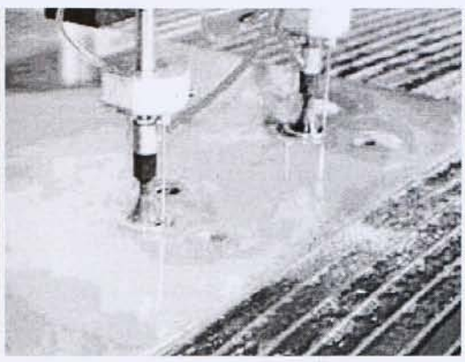


FABRICATION PROCESS

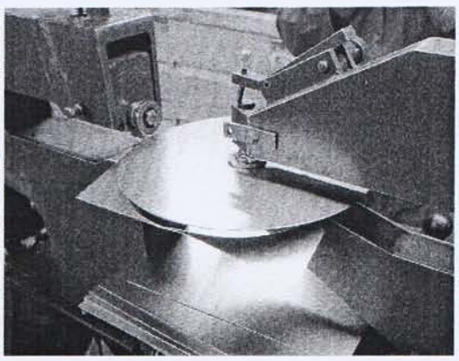
Cutting and shearing



Oxygen-flame and plasma cutting

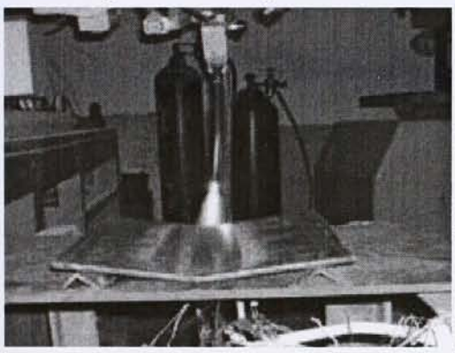


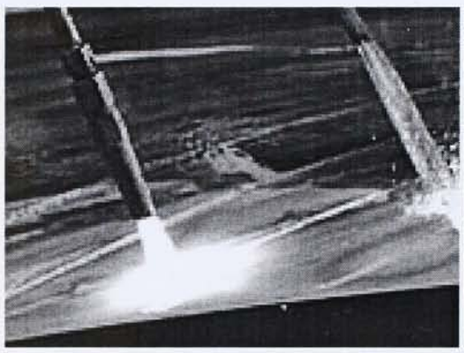
Water jet cutter



Circle cutting machine

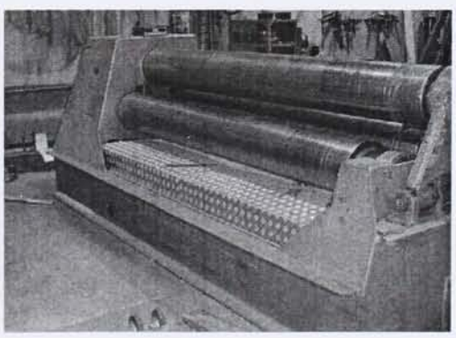
Bending and rolling

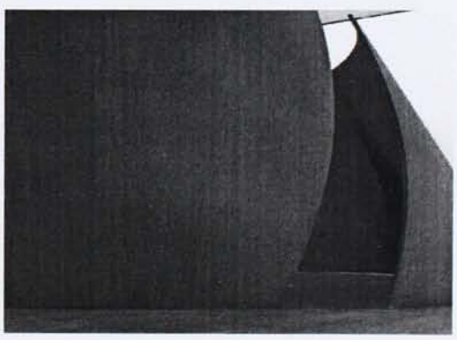




Line heating

Line heating is flame bending performed on metal plate, rather than rolled shapes, pipe, tube. While line heating can be used in a variety of steel fabrication activites, shipbuilding is its principal use. Steel hull hull plates vary in size but are typically 6 by 21 feet (2.3 by 6.5 meters). Hull plate can run from about 1/2 inch to serveral inches in thickness.





Cold Rolling

The metal sheet bending machine used for Richard Serra's sculpture is cold rolling. The roller is about 20 feet long. Picture two long steel rolls shaped like logs, about a foot in diameter each--with a larger one about two feet in diameter that comes between the two. You put the plate in between these three rollers and the middle one comes down, bending the plate. It's done very quickly. They turn on the machine and the plate rolls back and forth three times in three seconds, and you see metal fragments on the top surface crack and pop off like dust.

MATERIAL CONSIDERATION AND DETAILING

Aluminum is selected as the materal of the bending suface, because of its light weight property. The density of aluminum is 2700 kg/m^3, compared to steel 7900 kg/m^3. The structural aluminum alloys (alloy 5083) achieve 345 N/mm^2, comparable to the 410-560 N/mm^2 for S275 steel. Therefore, aluminum alloy can offer better strength to weight basis.

There are nine series of aluminum alloy with different alloying elements. Each of them has different applications and are listed as followed.

Alloy series	Alloying element	properties	Applications
1xxx	None	Excellent corrosion resistance, high thermal and electrical conductivities, low mechanical properties, excellent workability	Chemical Equipment, reflectors, heat exchangers, electrical conductors
2xxx	Copper	Heat treatable, high strength to weight ratio, limited corrosion resistance, limited weldabilty	Truck wheels, truck suspension components, aircraft fuselage
3xxx	Manganese	Moderate strength without heat treating	Beverage cans, cooking utensils, heat exchangers, storage tanks
4xxx	Silicon	Low thermal expansion, high wear resistance	Forged engine pistons, welding rod, brazing alloys, architectural products,
5xxx	Magnesium	Good weldability, good corrosion resistance	Ornamental trim, cans, household appliances, boats and ships
6xxx	Magnesium and Silicon	Heat treatable, good formability, moderate-strength, good weldability, good machinability, good corrosion resistance	Architectural applications, bridge railings, welded structures, racecar components
7xxx	Zinc	Heat treatable, moderate to very high strength	Airframe structures, high-strength forgings
8xxx	Other elements	N/A	N/A
9xxx	Unused series	N/A	N/A

Because of the weldability and strength, the fifth and sixth series of aluminum alloy will be the first two material consideration.

PART2: EXPERIMENTS OF FORM VARIATION

This part will focus on exploring the geometrical variation of structure and module.

Different modeling procedures will be experimented and two main challenges of the experiments are listed as followed.

1) How can the circle packing pattern be done on a surface wtih double curvature
2) The modules can be adjusted automatically to fit different types of double curvature and the fabrication possibility of the bending surface is maintained

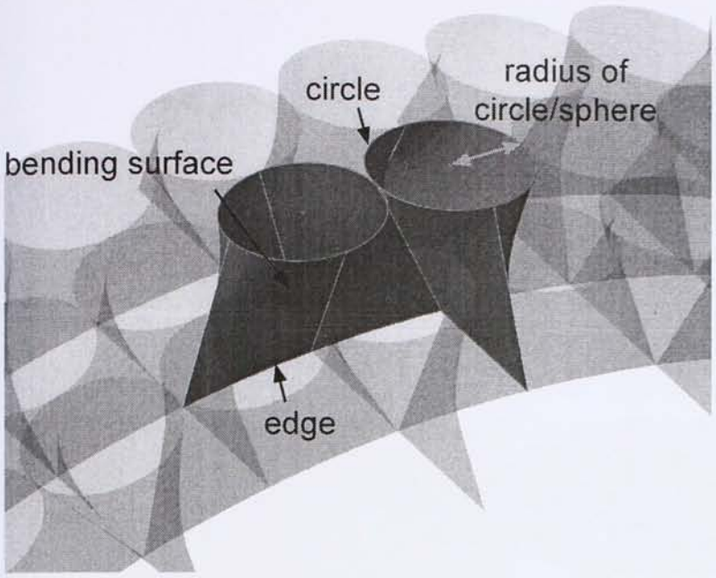
The following are the main constraints in all experiments
1) The circle of the modules has to be touching to that of the adjacent modules
2) The modules has to be positioned perpenicular to the adjacent modules.
3) The two ends of the edges has to be the projection of centre points of the adjacent circle
4) The surface is formed by the circle and the edge in each module

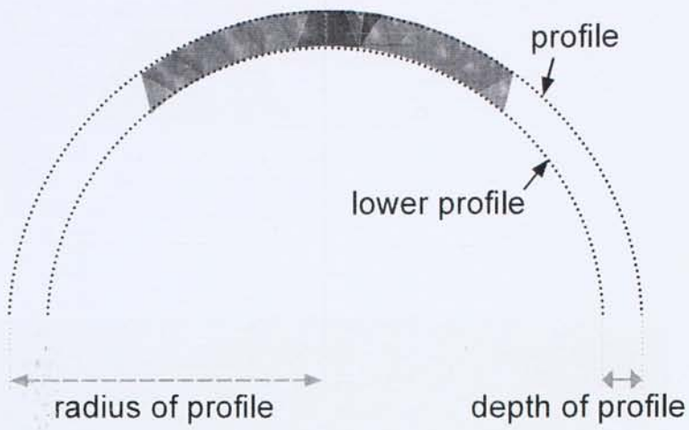
With the structural and fabrication consideration, 'prefect ring' and 'perpendicular relationship to the adjacent components' are the two main constraints in this stage of form exploration. Whether than a free from without appropriate reference for generating the form, this is a more formal way to describe the form. Setting the key parameters, appropriate formula and order to achieve the most form variation become the most critical task in this part.

A series of experiments have been tried out to pack the components with different forms (flat, arch, spherical surfaces, double curvature) with the constraints mentioned. Finally, the double curvature controlled by two parameters (profile radius and path radius with positive and negative directional variables) becomes the universal model for the next stage of exploration.

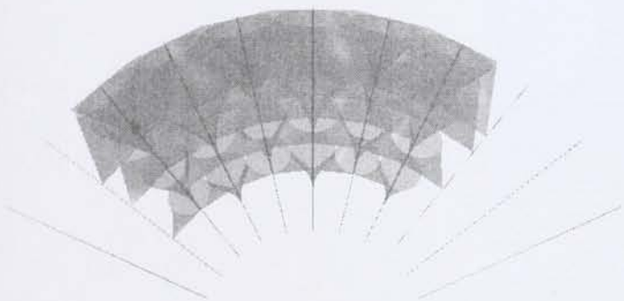
GEOMETRICAL RELATIONSHIP

Experiment	1	2	3	4	5	6
Profile	Flat	Arch	Sphere	Sphere	Sphere	Double curvature
Modeling method						
Pre- drawn Profile	No	No	No	Yes	Yes	Yes
Module	Circle and Edge	Circle and Edge	Circle and Edge	Polyline and 5 points	Circle and 5 points	Sphere and 5 points
Depth of Profile	N/A	N/A	N/A	Offset	Pre- drawn lower profile	Determined by the radius of each sphere
Grid of circle packing						
XZ plane	N/A	N/A	N/A	Evenly radical division	Parallel to XZ plane Division is determined by the centre point of circle	Parallel to XZ plane Division is determined by the centre point of sphere
YZ plane	N/A	N/A	N/A	Evenly radical divsion	Evenly radical divsion	Evenly radical divsion
Flipping (Concave and convex)	No	No	No	No	No	Yes
Parameter	Radius of circle Angle	Radius of circle Angles of two types of modules	Radius of circle Angles of two types of modules	Radius of profile Depth of profile	Radius of profile Radius of the first circle Depth of profile	2 Radius of profile Radius of the first circle Flipping Ratio of depth to radius

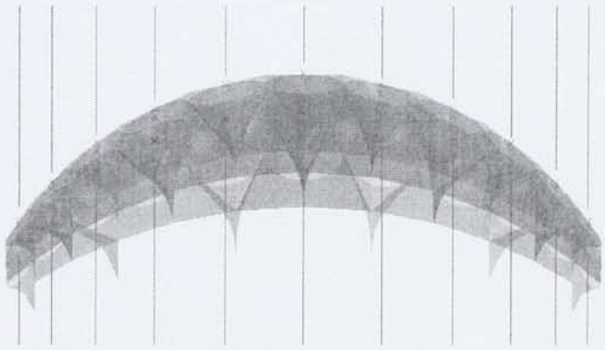




Grid of circle
packing

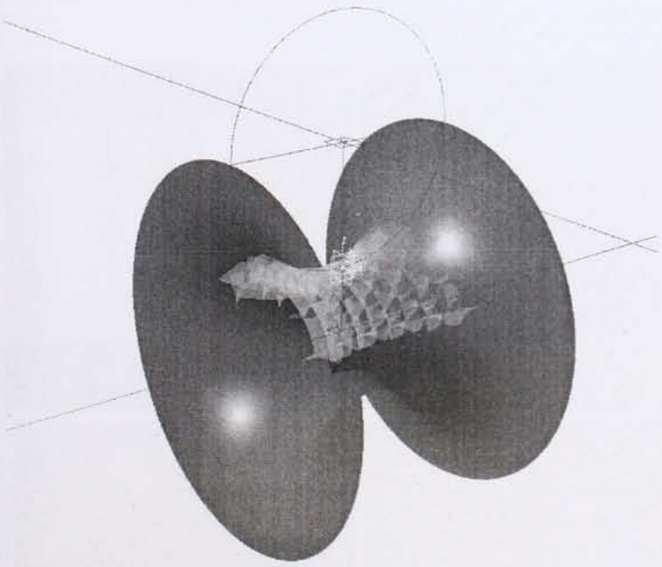


Evenly radical division

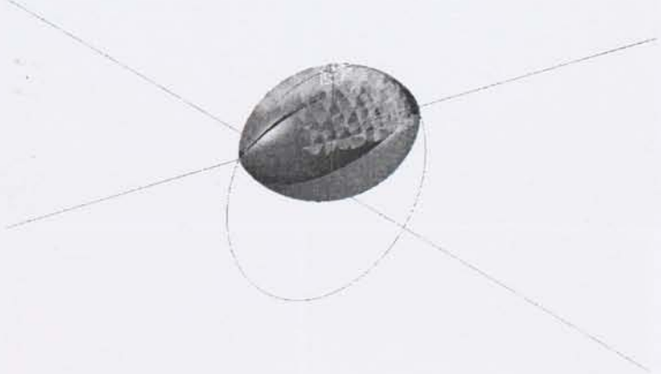


Parallel to XZ plane
Division is determined by the centre point of circle

Flipping

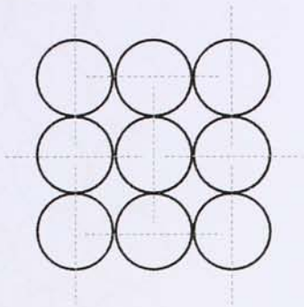


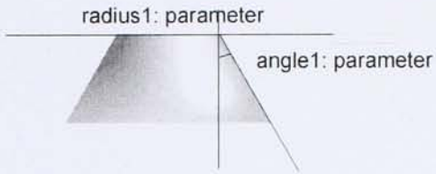
Concave

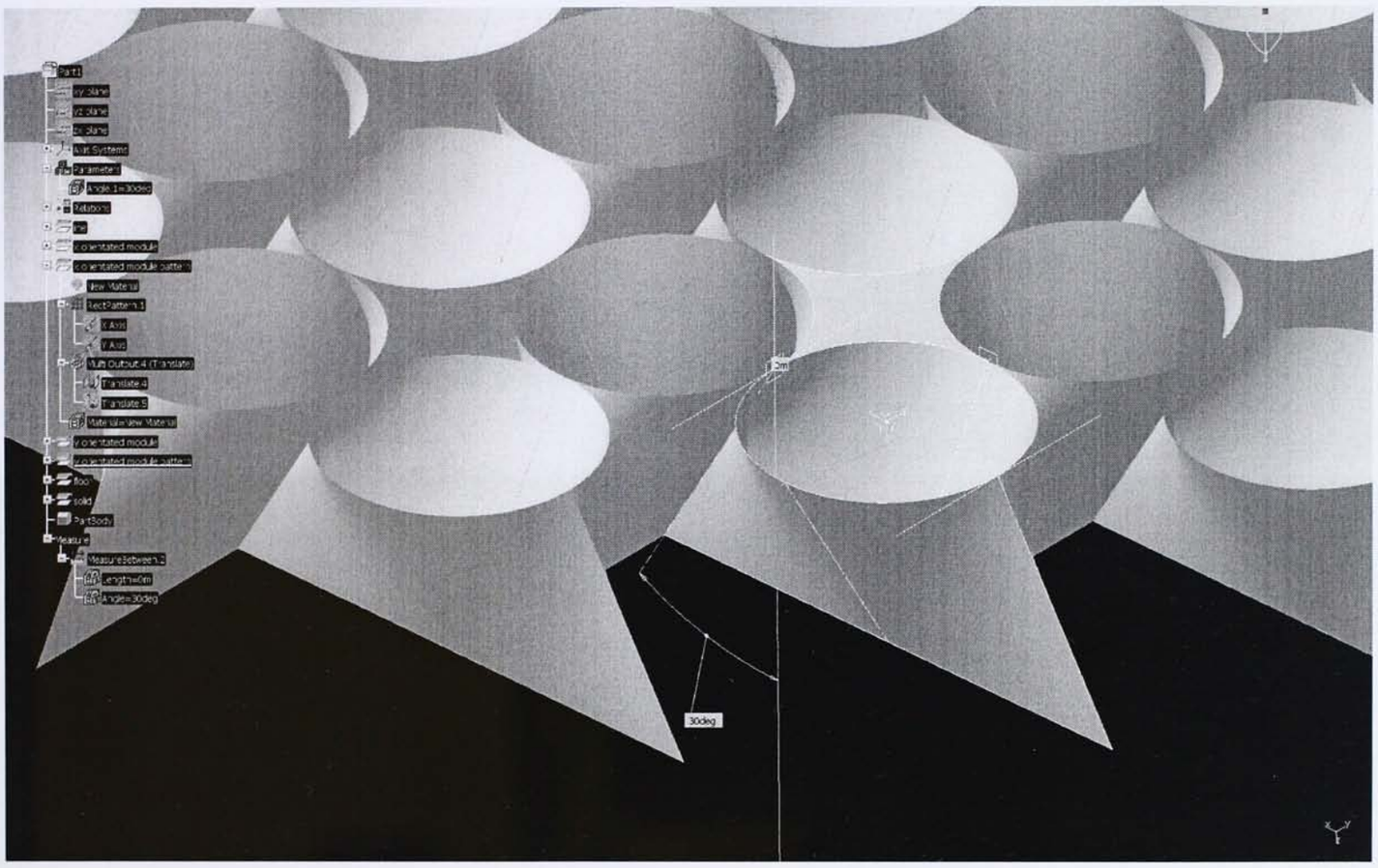


Convex

Experiment1: A basic testing of the parametric modeline. A flat profile is composed by one type of module. The angle of the module is a parameter to determine the depth of the profile.

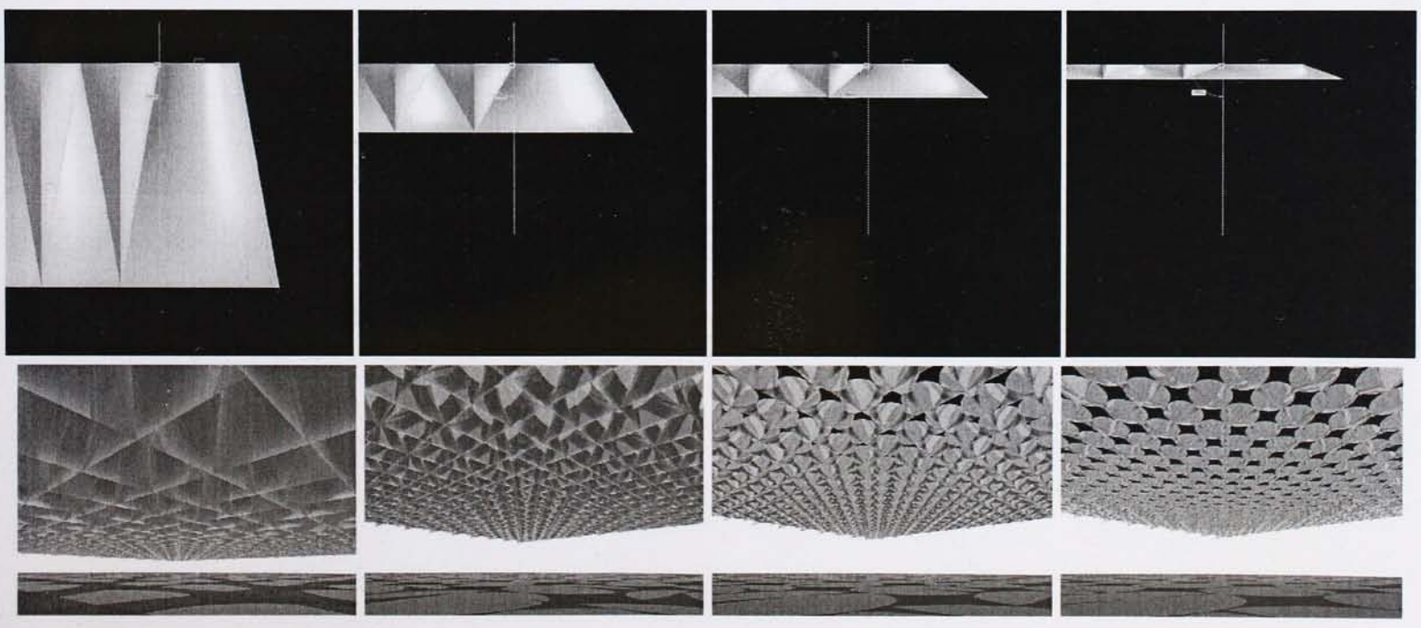




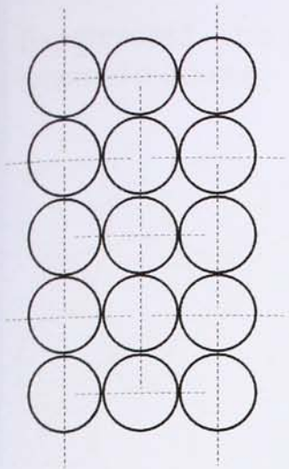


Module inclined edge angle:

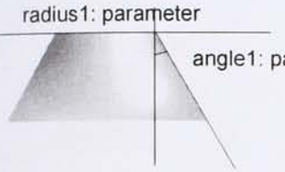
10 30 50 70



Experiment2: An arch profile is composed by two types of modules with different angles.

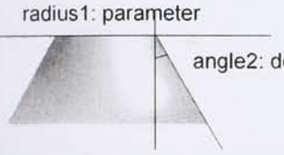


radius1: parameter

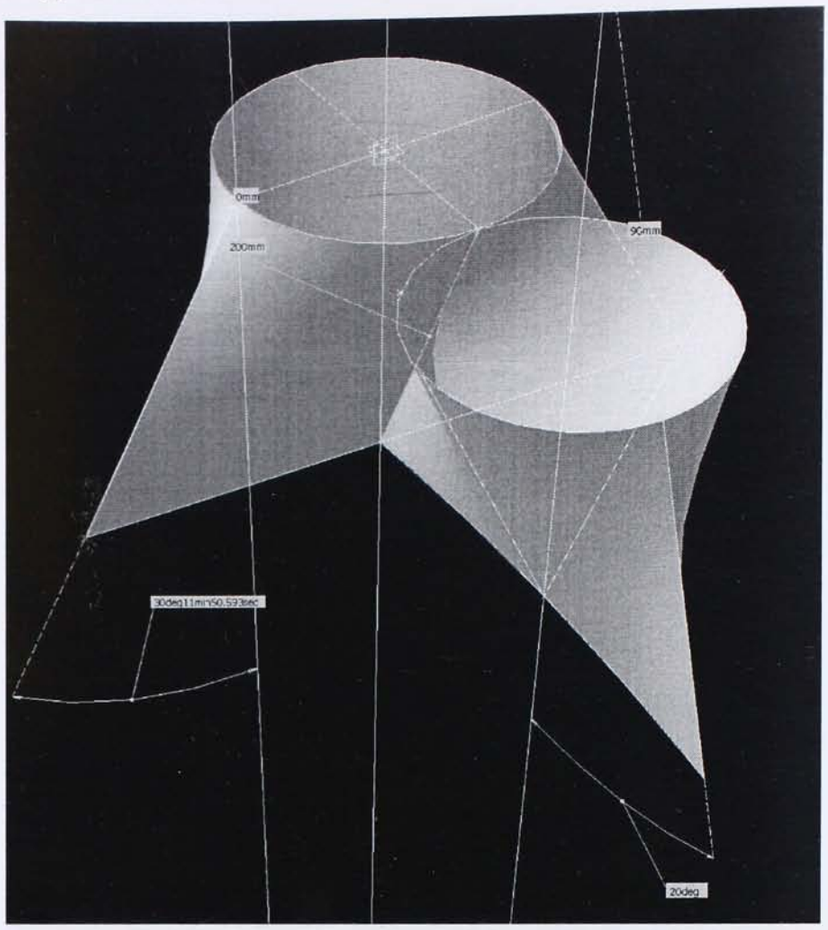


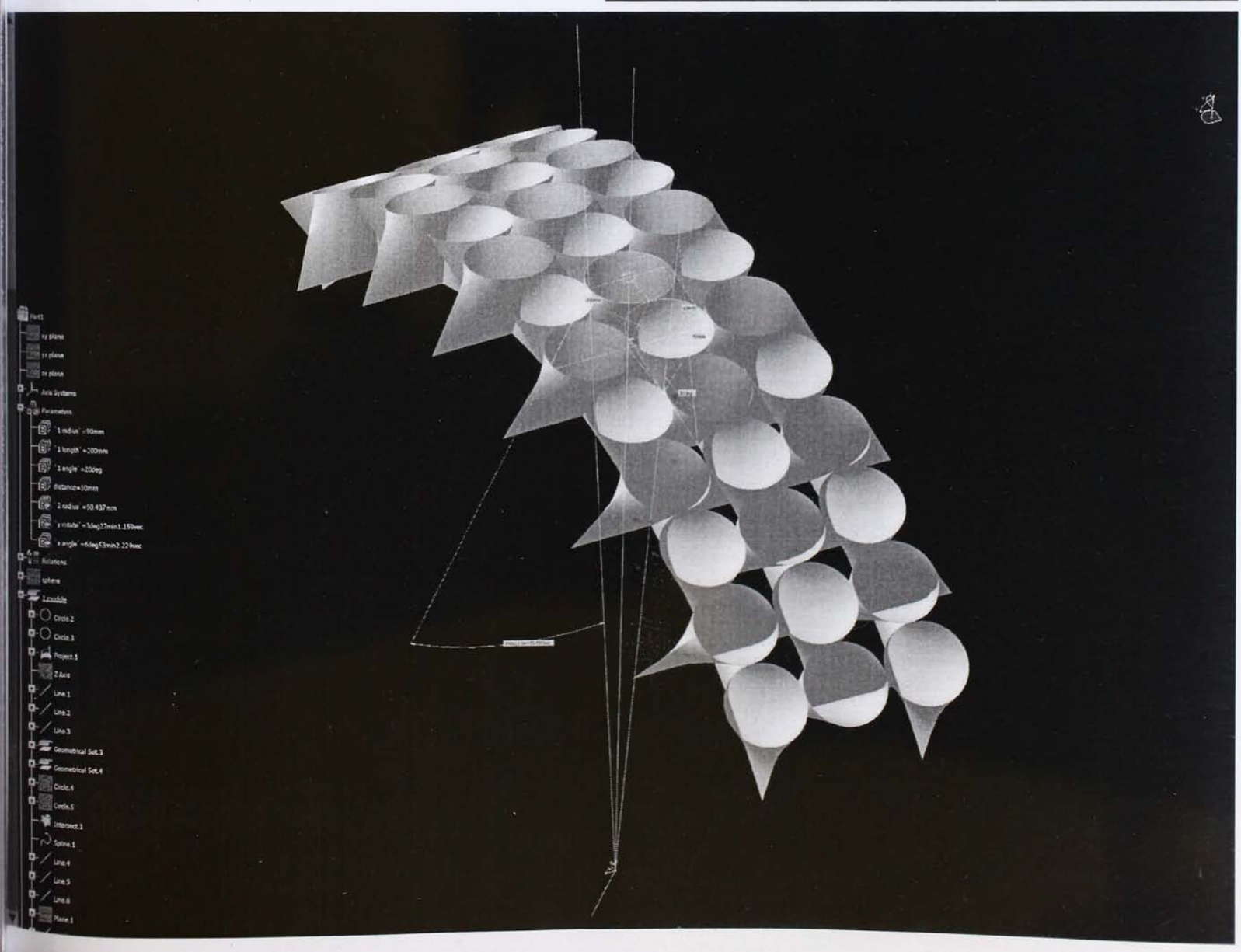
angle1: parameter

radius1: parameter



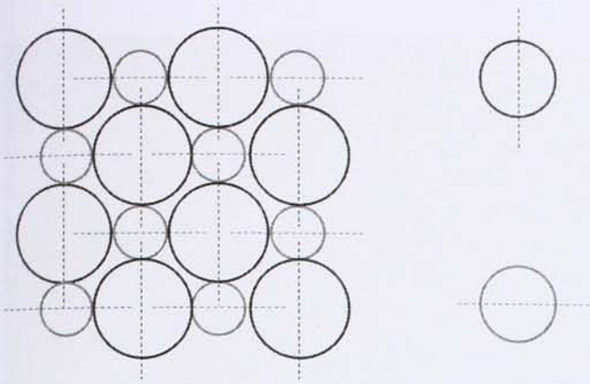
angle2: determined by angle1, radius and edge

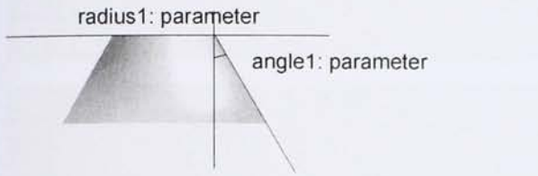


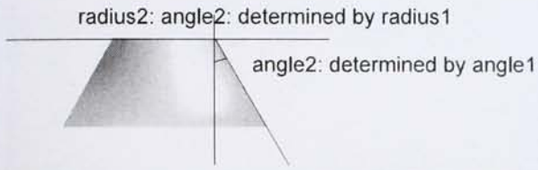


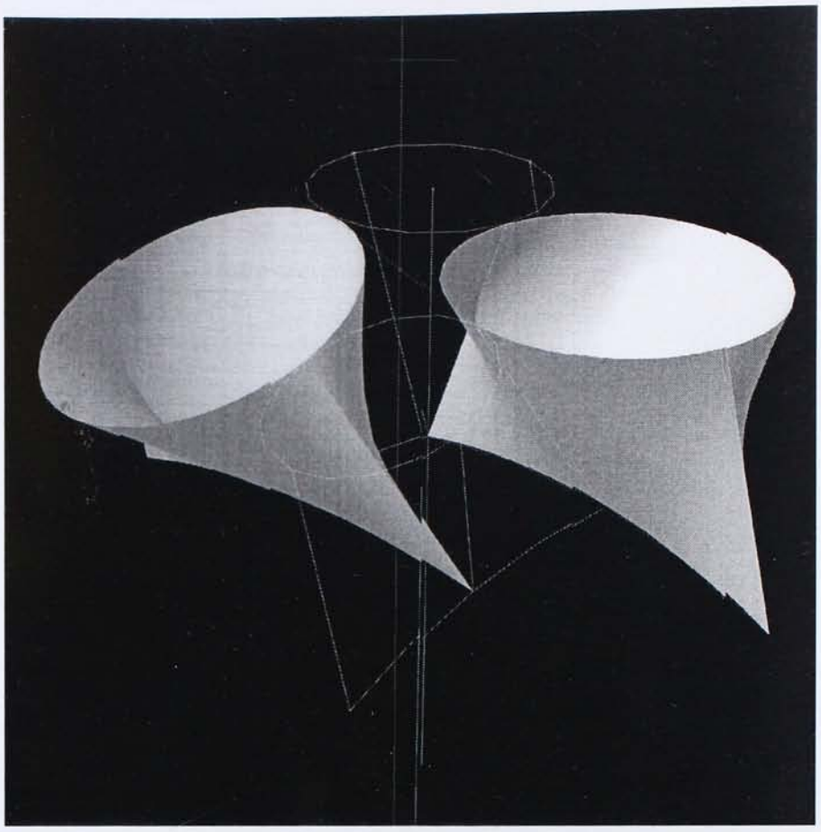
GEOMETRICAL RELATIONSHIP

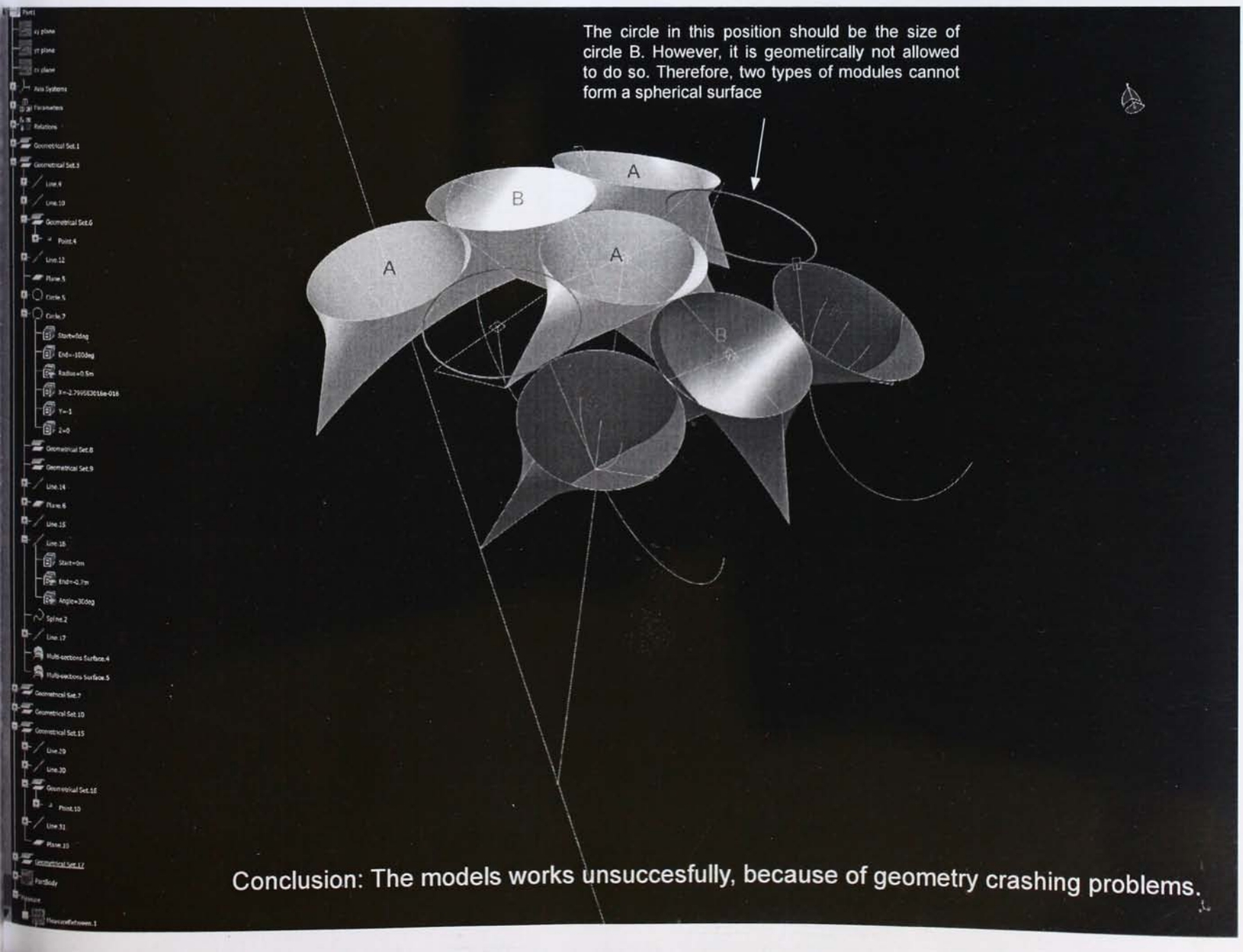
Experiment3: This experiment is to test out whether a double curvature can be composed by two types of modules.





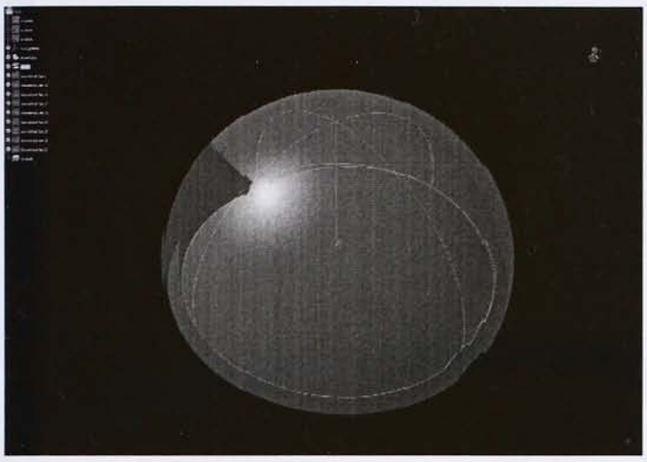




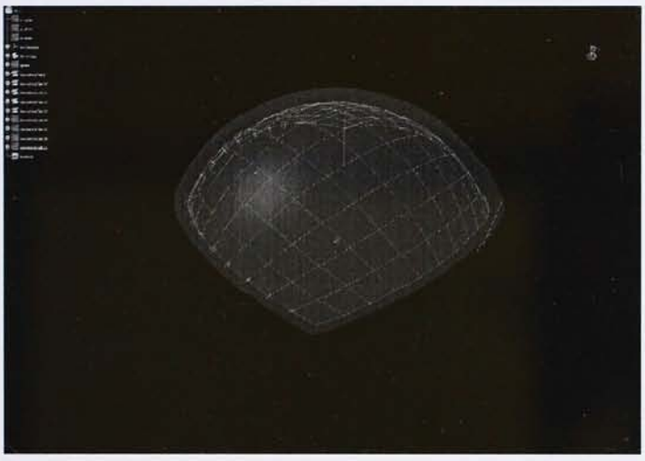


Conclusion: The models works unsuccesfully, because of geometry crashing problems.

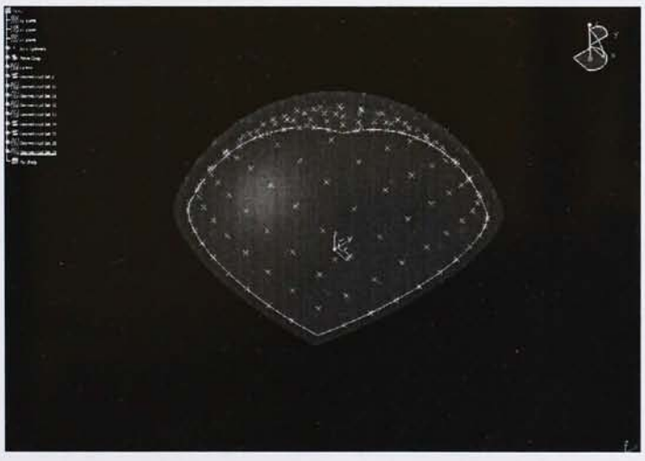
Experiment4: Reviewing the experiment 3, this experiment is trying to set up the profile first before consider the geometry of the modules. Modules will be generated by the grid and control points on the pre-drawn profile.



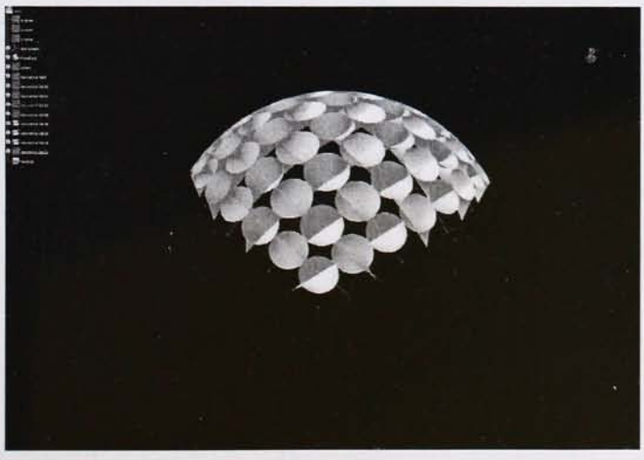
Step 1 A spherical surface is drawn as a profile



Step 2 Evenly radical divisions in XZ and YZ planes divided the surface and generated a grid on the spherical surface.



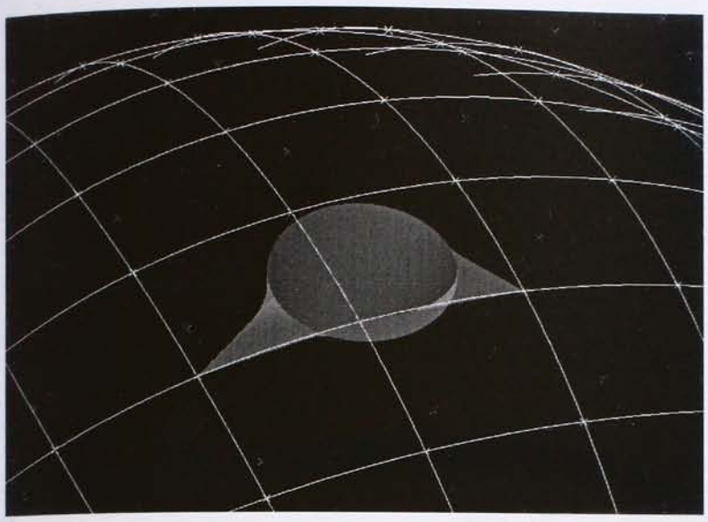
Step 3 Control points are generated by the grid.

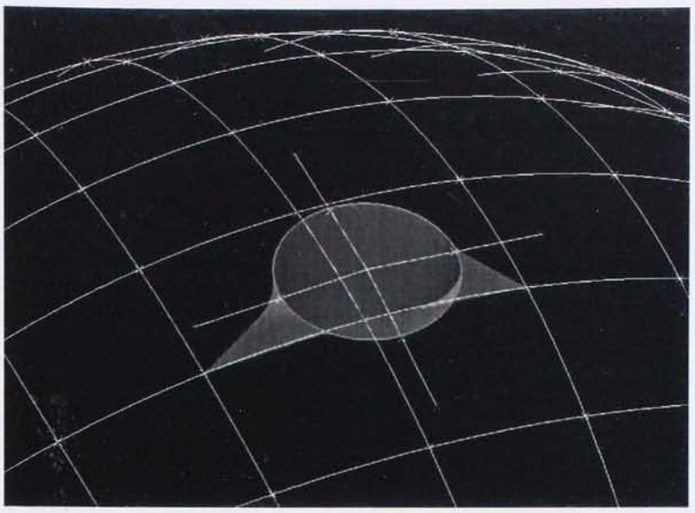


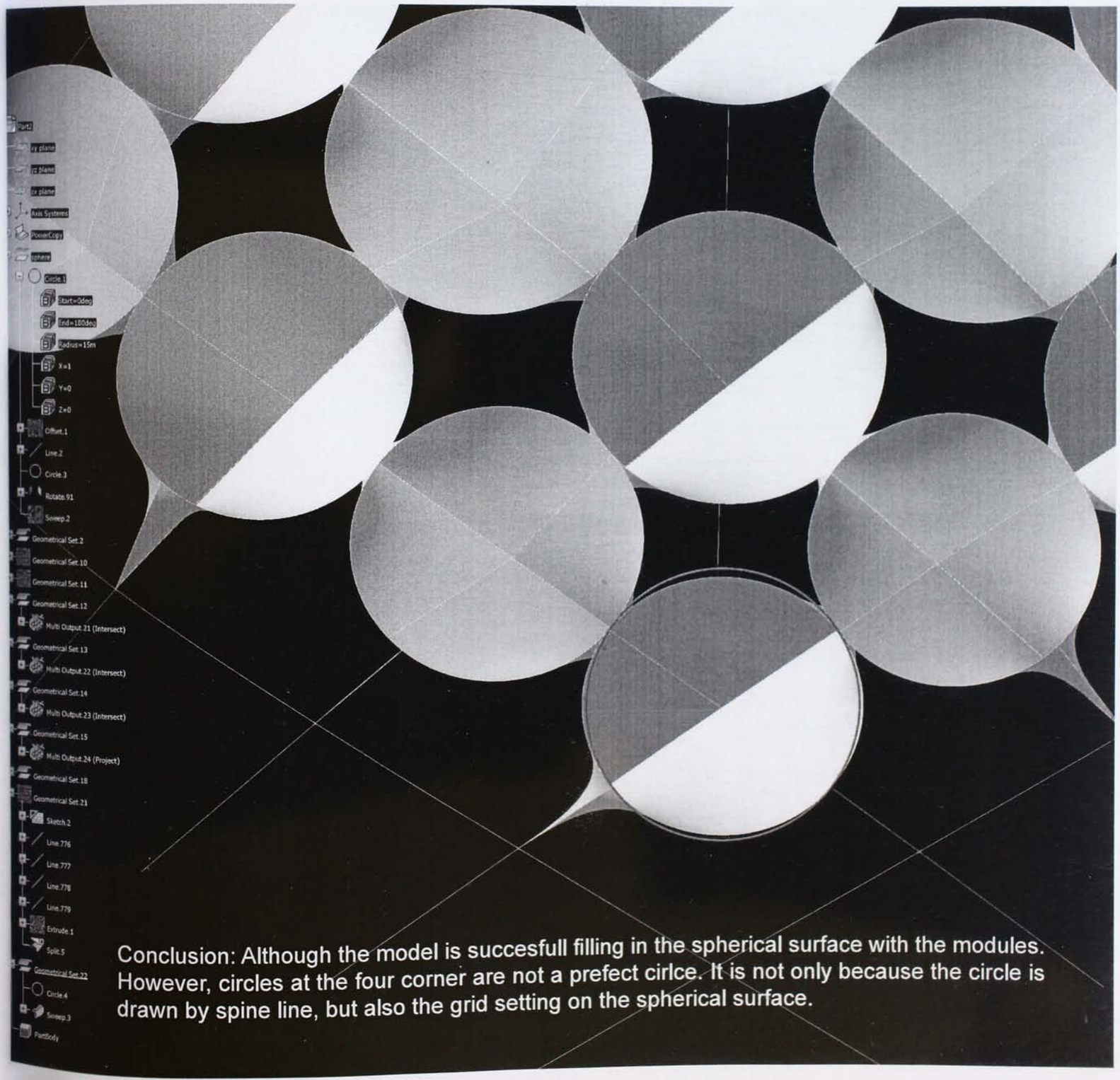
Step 4 Modules are defined and generated based on the control ppoints.

The modules are defined by the control points generated by the intersection of two divisions

The circle is drawn by spine line defined by the mid-points between the centre point and the central points of the four adjacent centre points.







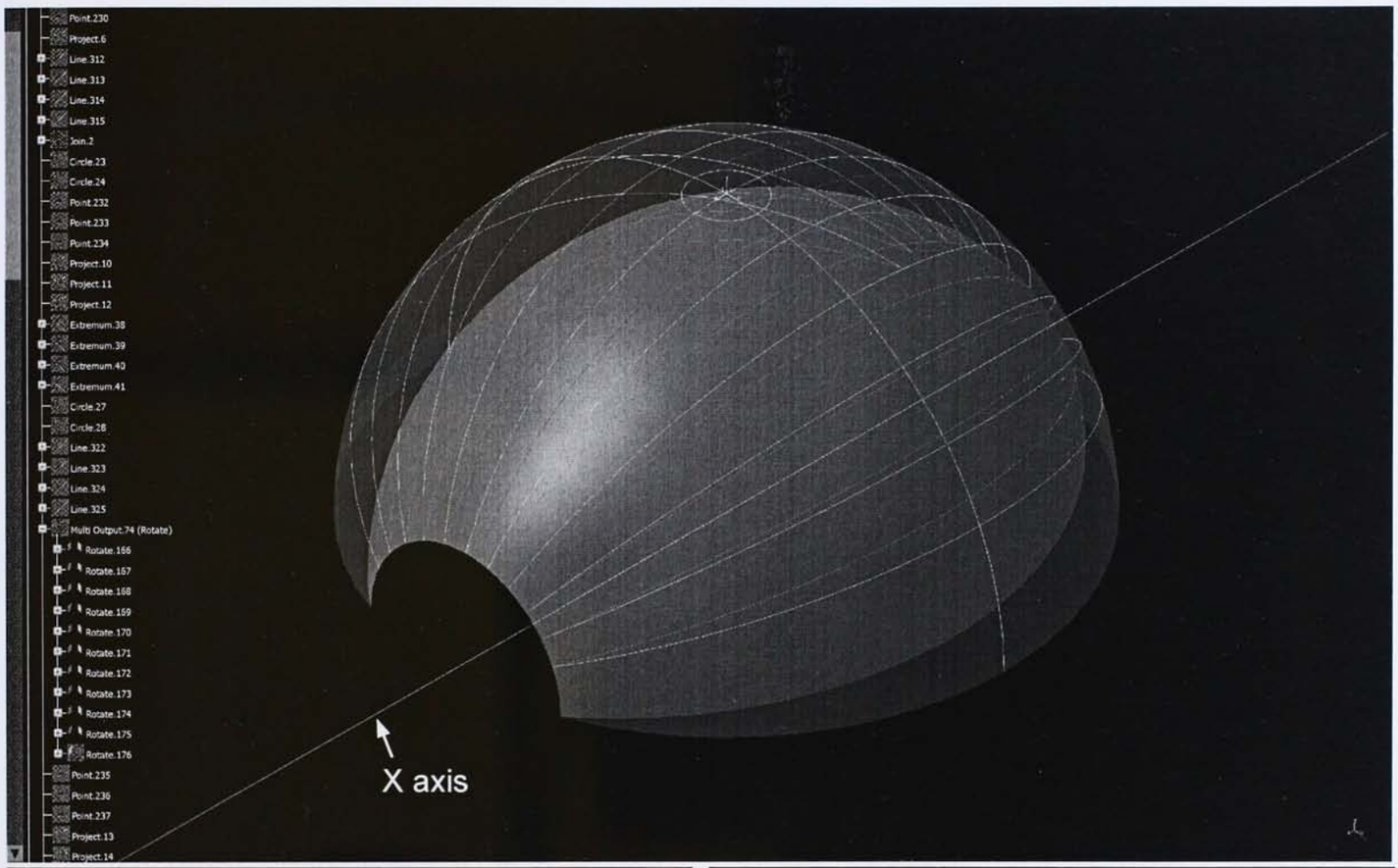
Conclusion: Although the model is succesfull filling in the spherical surface with the modules. However, circles at the four corner are not a prefect cirlce. It is not only because the circle is drawn by spine line, but also the grid setting on the spherical surface.

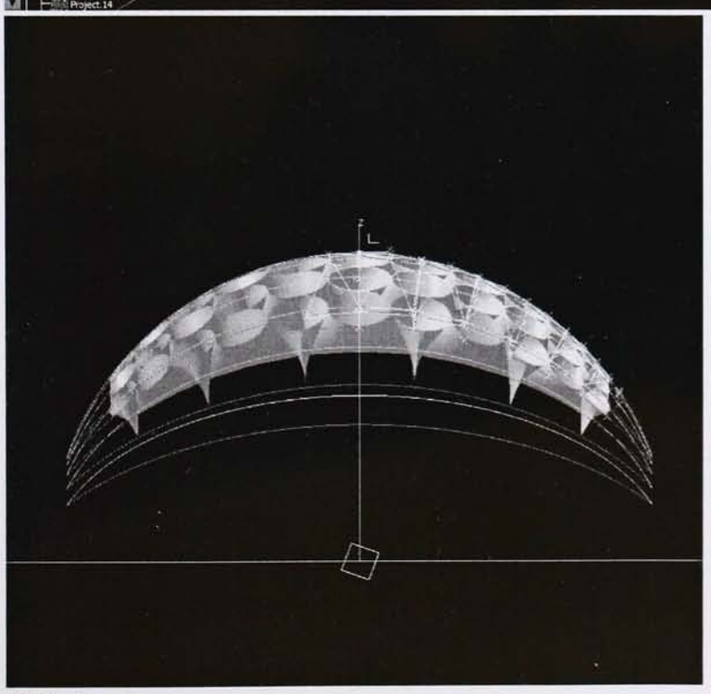
Experiment5: This experiment has tried out a new grid setting on the spherical surface. The strategy is to draw the first row of circle. By rotation of the row of circles, the spherical surface can be packed by the circles.

The rotation of the first row of circles is along X axis. The grid of XZ plane will be parellal to YZ plane and positioned according to the centre points of circles. The grid of Y plane will be evenly radical division.

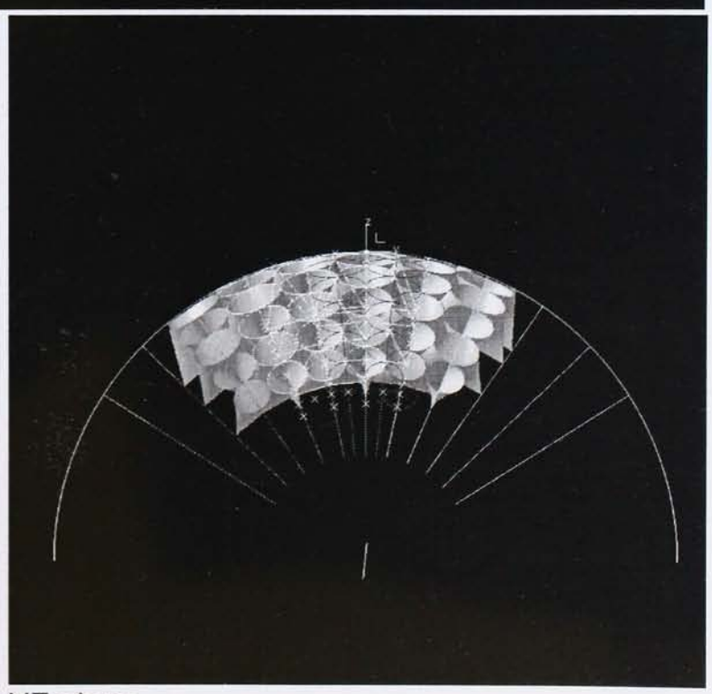
The depth of profile will be determined by a lower profile which has lower curvature, so the smaller modules at two ends of the structure will have less depth.

The main challenge in this experiment is how to set up the first row of circles with variable radius.



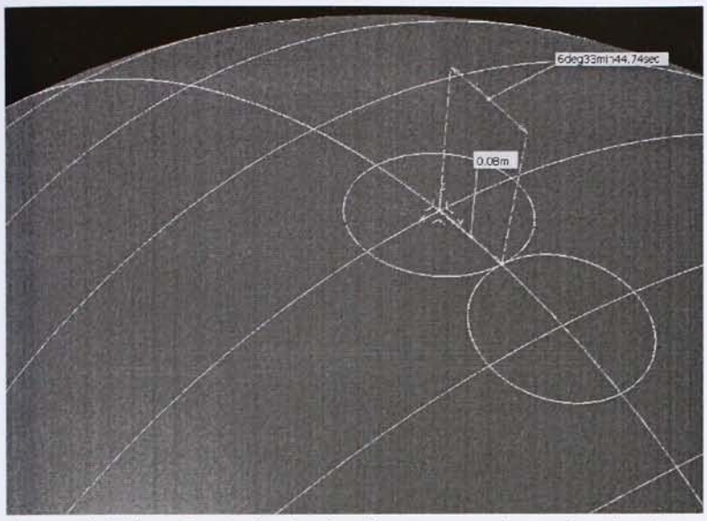


XZ plane

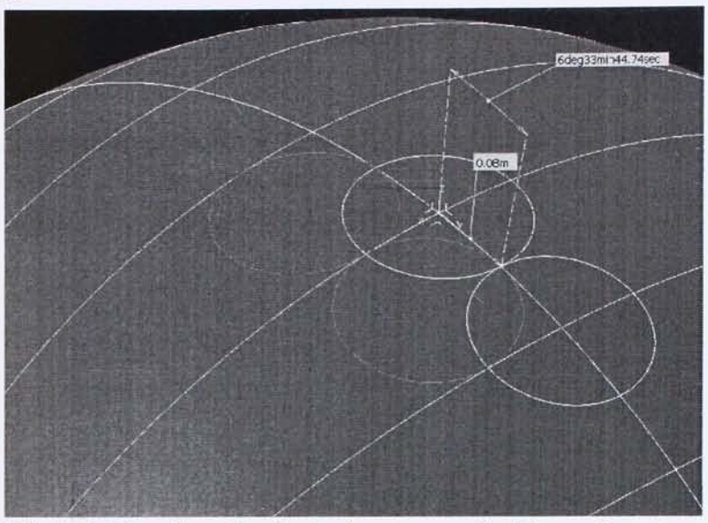


YZ plane

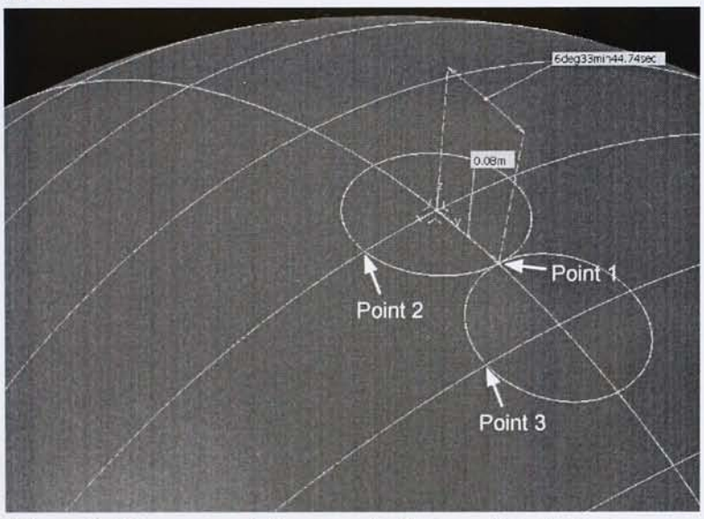
Setting up the first row of circles with variable radius



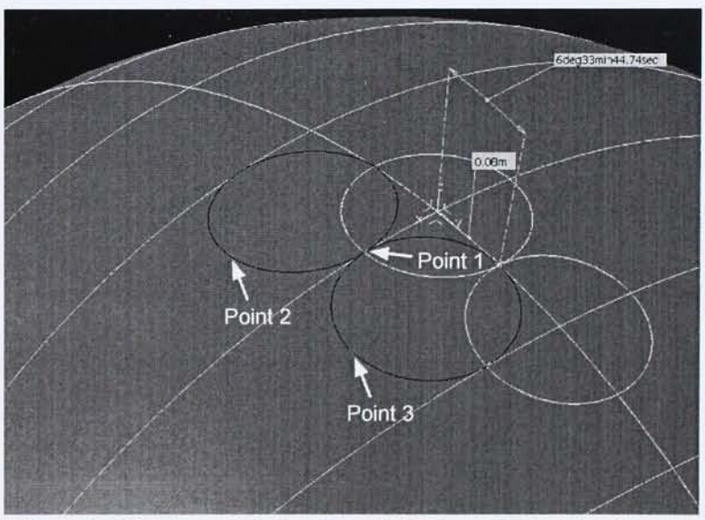
Step 1 The first circle is drawn and projected on the spherical surface. The second circle is drawn by rotation of the first cirle with the angle measured between the centre point of first circle, centre point of the profile and the extreme point in Y axis



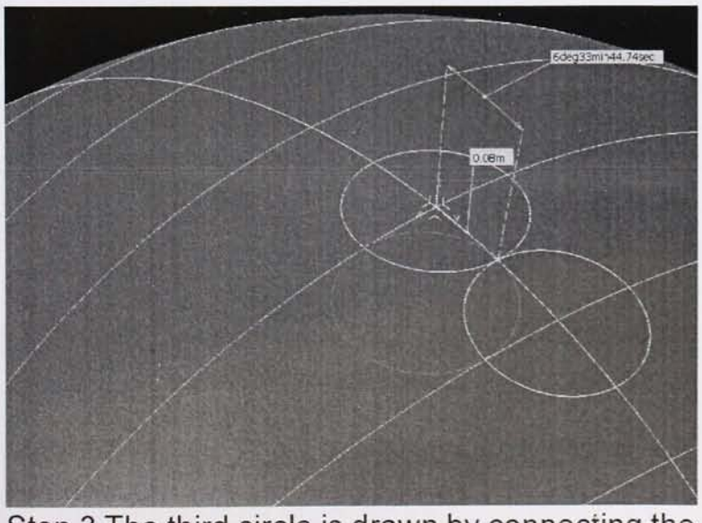
Step 4 The fourth circle is generated by mirroring the third circle with the XZ plane



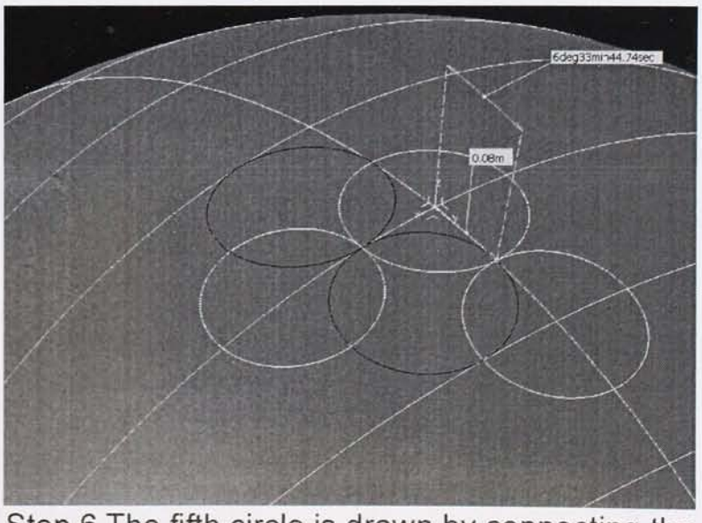
Step 2 Three points for defining third circle are generated based on the first two circle.
Point 1: Extreme point of first circle in Y axis
Point 2: Extreme point of first circle in X axis
Point 3: Extreme point of secdon circle in X axis



Step 5 Three points for defining fifth circle are generated based on the third and fourth circle.
Point 1: Extreme point of fourth circle in Y axis
Point 2: Extreme point of third circle in X axis
Point 3: Extreme point of fourth circle in X axis



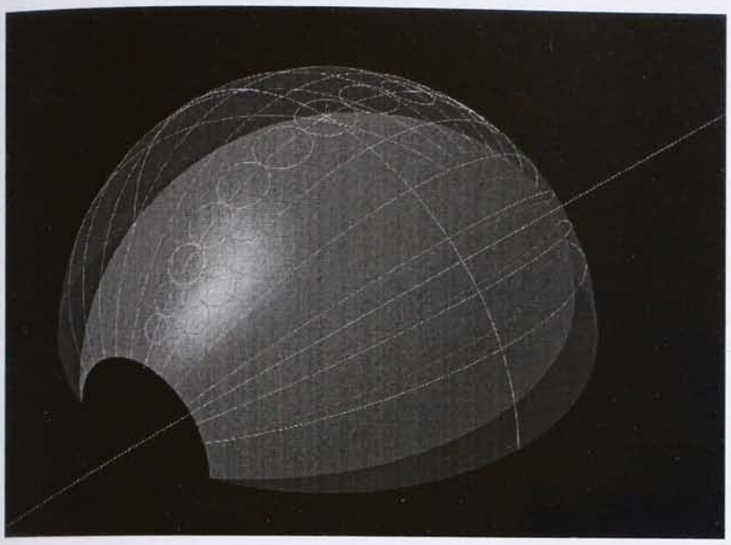
Step 3 The third circle is drawn by connecting the three points.

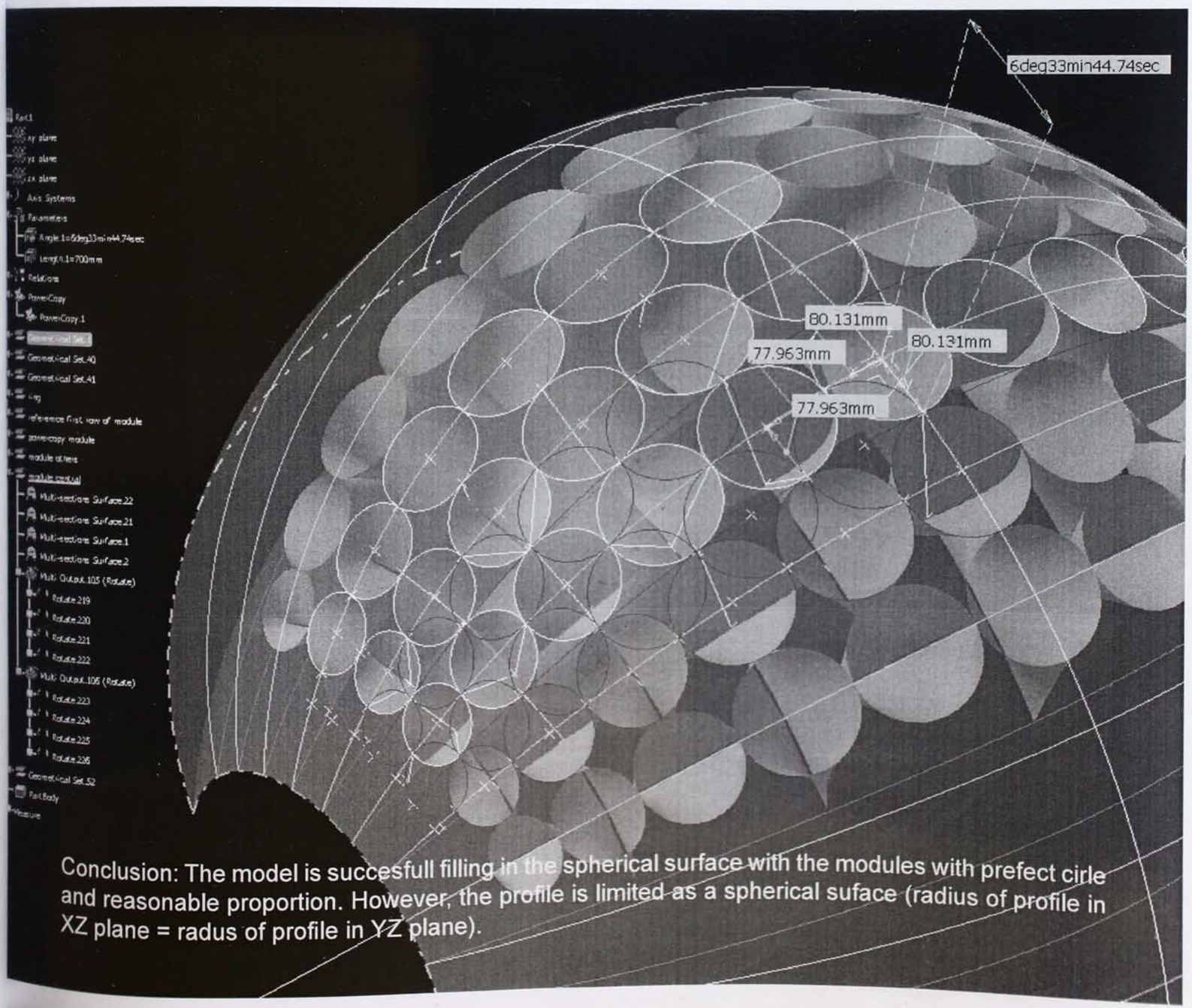


Step 6 The fifth circle is drawn by connecting the three points.

Using the 6 steps method mentioned in the last page, the first row of circle can be generated. Each circle is touching to the adjacent circle and fit to the spherical surface. The circles have different radius and be able to rotated and touching the adjacent row of circles.

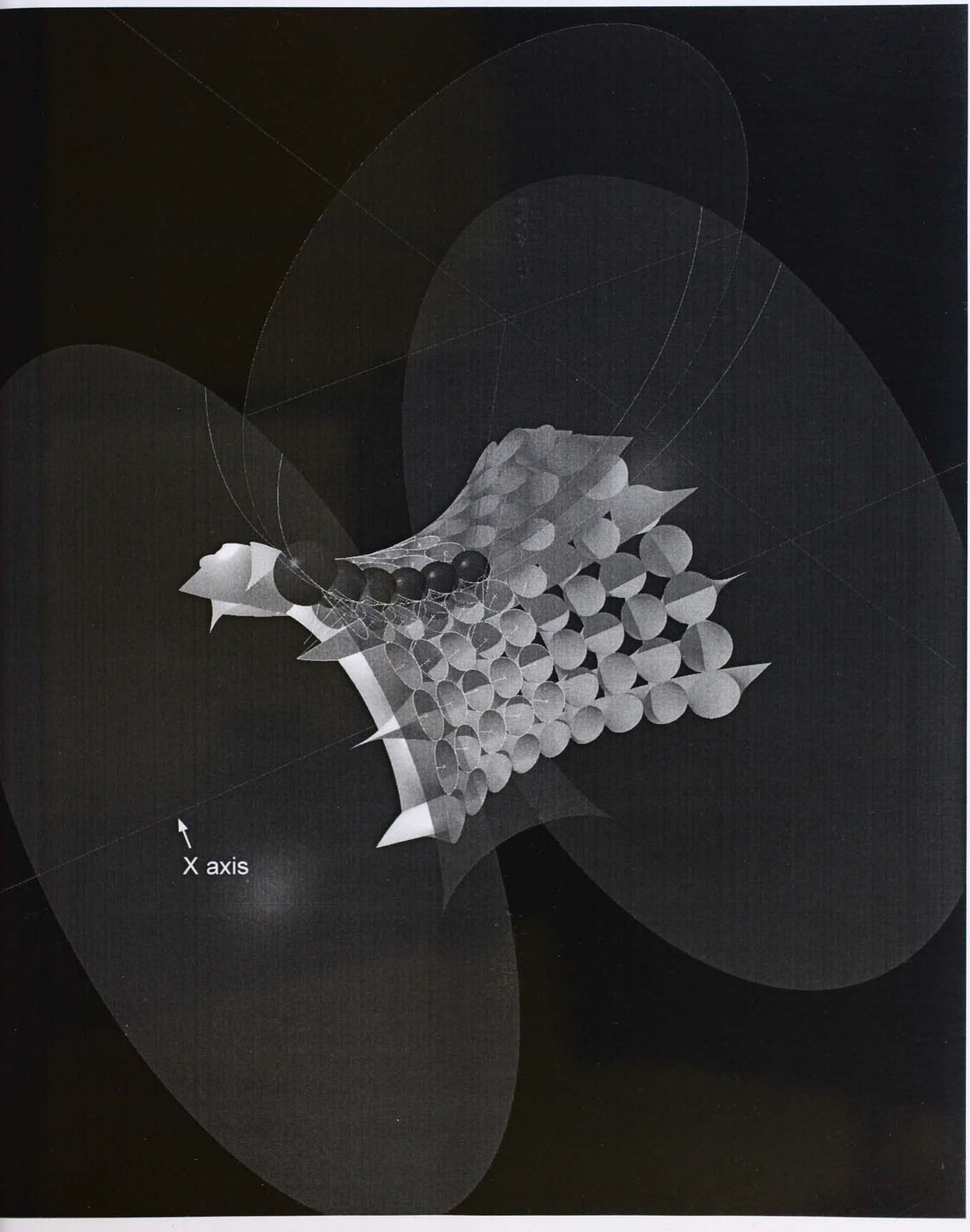
The depth of the profile is define by a lower profile. The lower profile in this experiment have a smaller degree of curvature. Therefore, the larger modules in the middle part of the structure have more depth. This can maintain the proportion of each modules and prevent over bending of the surface.



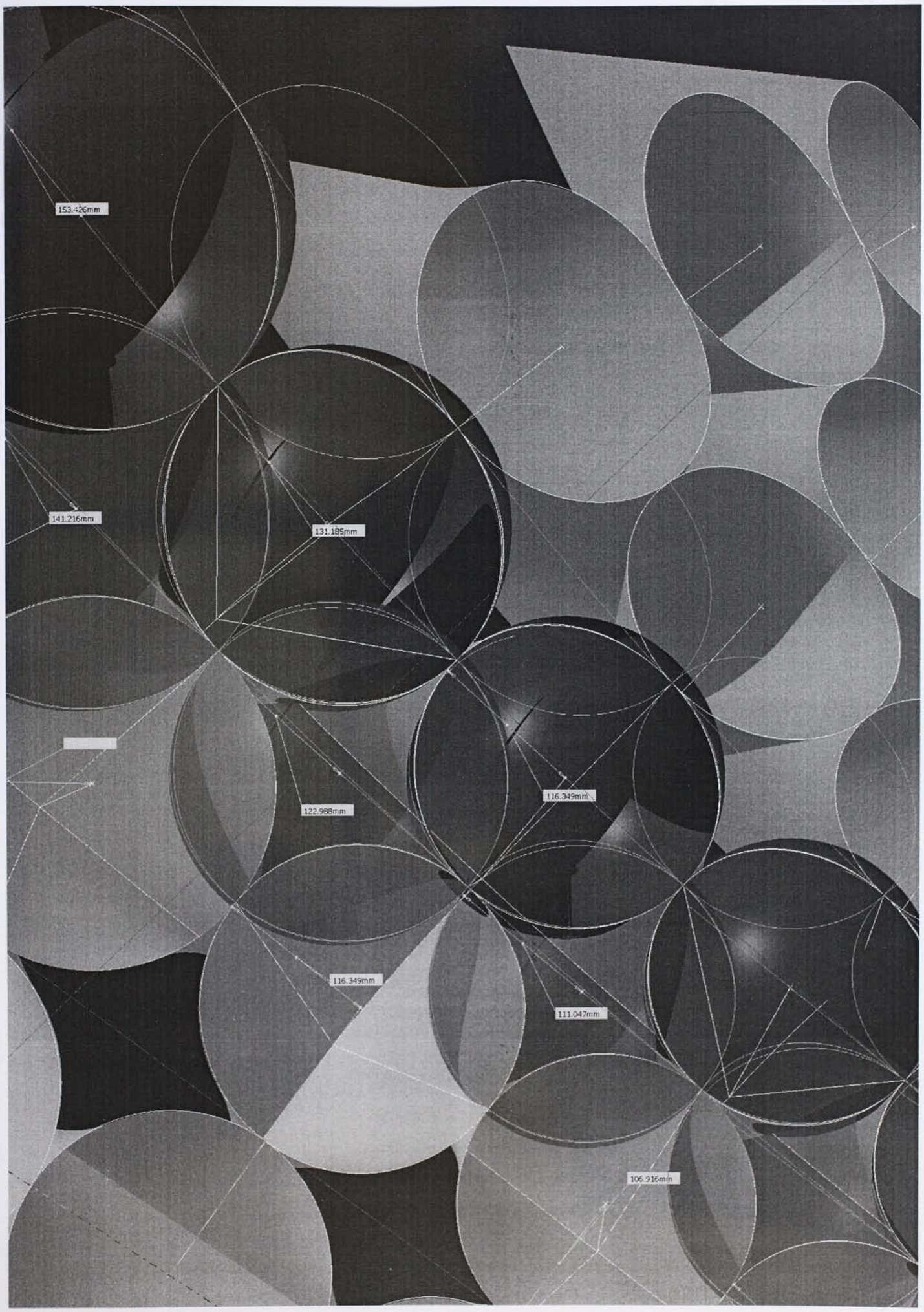


Conclusion: The model is succesfull filling in the spherical surface with the modules with prefect cirle and reasonable proportion. However, the profile is limited as a spherical suface (radius of profile in XZ plane = radus of profile in YZ plane).

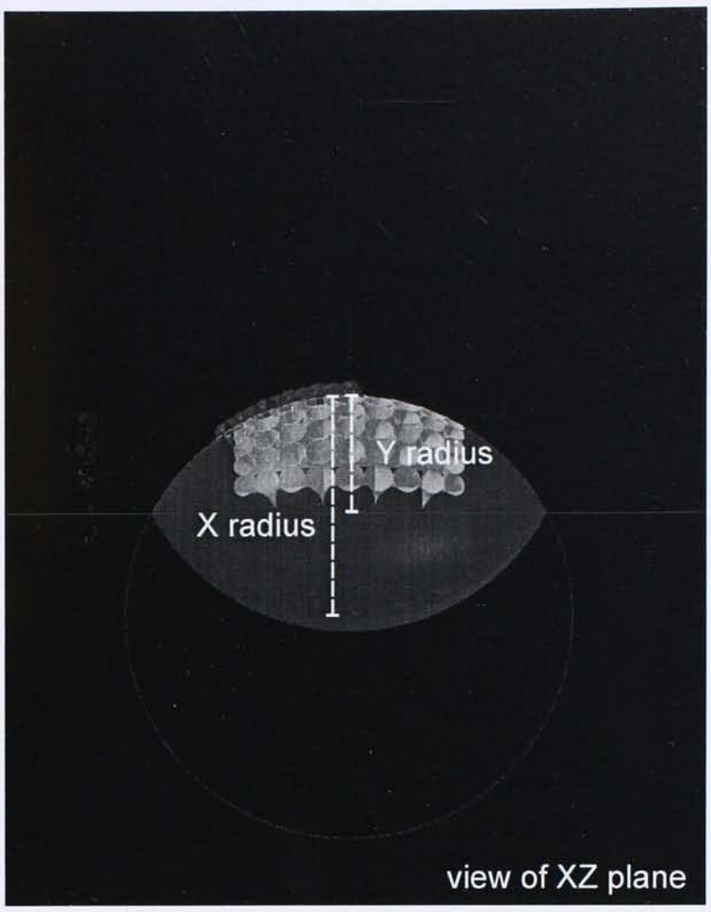
Experiment6: This experiment test out the method to fill in the modules on a more flexible double curvature, including concave and convex curvature and different degree of curvature on XZ plane and YZ plane. The depth of profile is no longer defined by a lower profile, but determined by the radius of each circle of modules. Therefore, the depth of profile can be adjusted in different cases of double curvature.



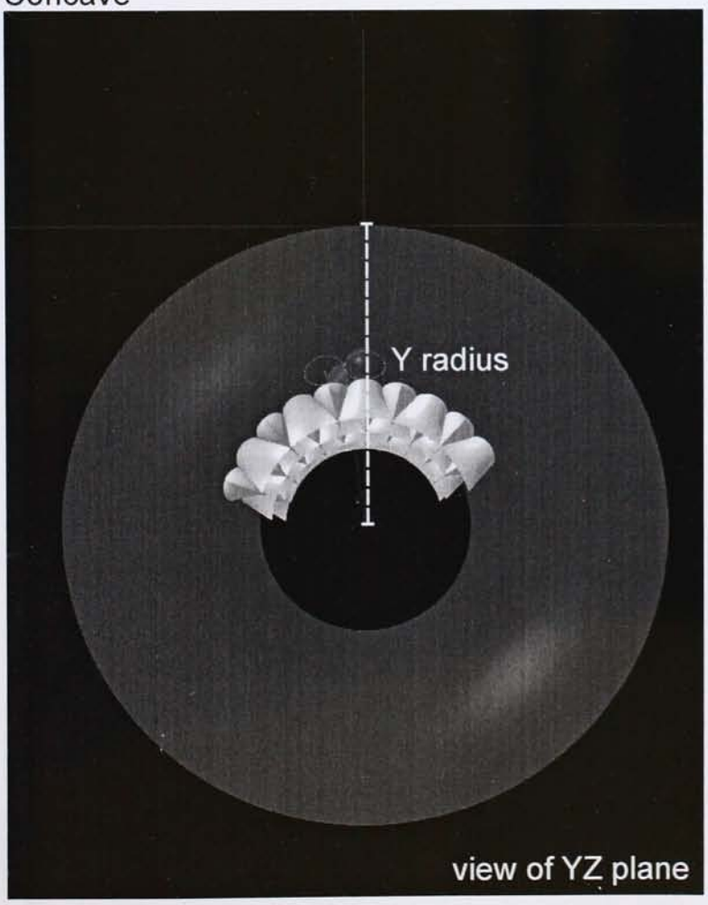
Instead of circle, sphere is used to define the size of ring on the double curvature surface.

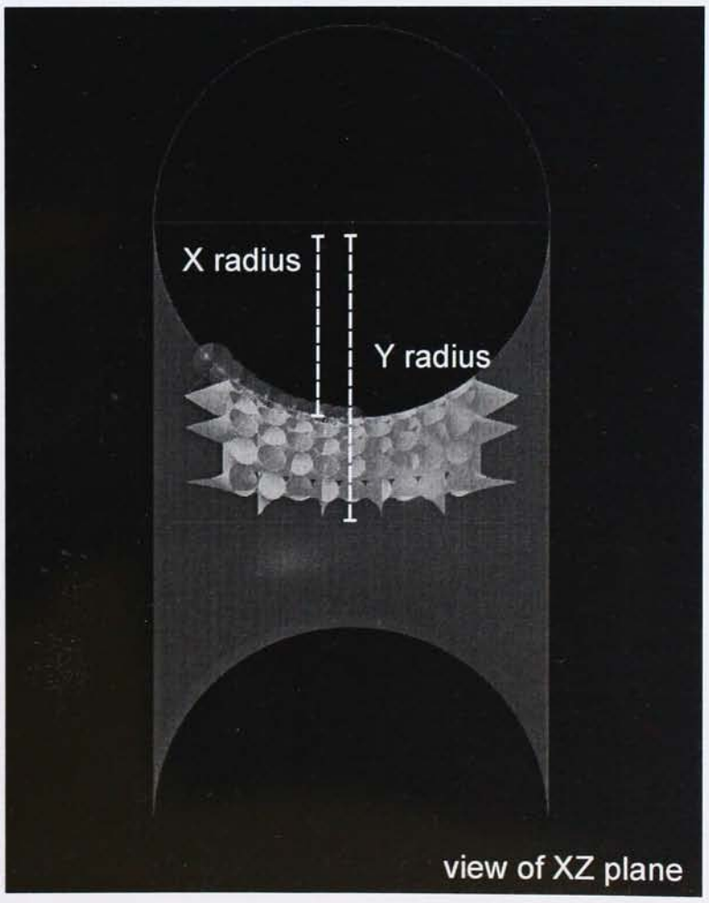


Convex

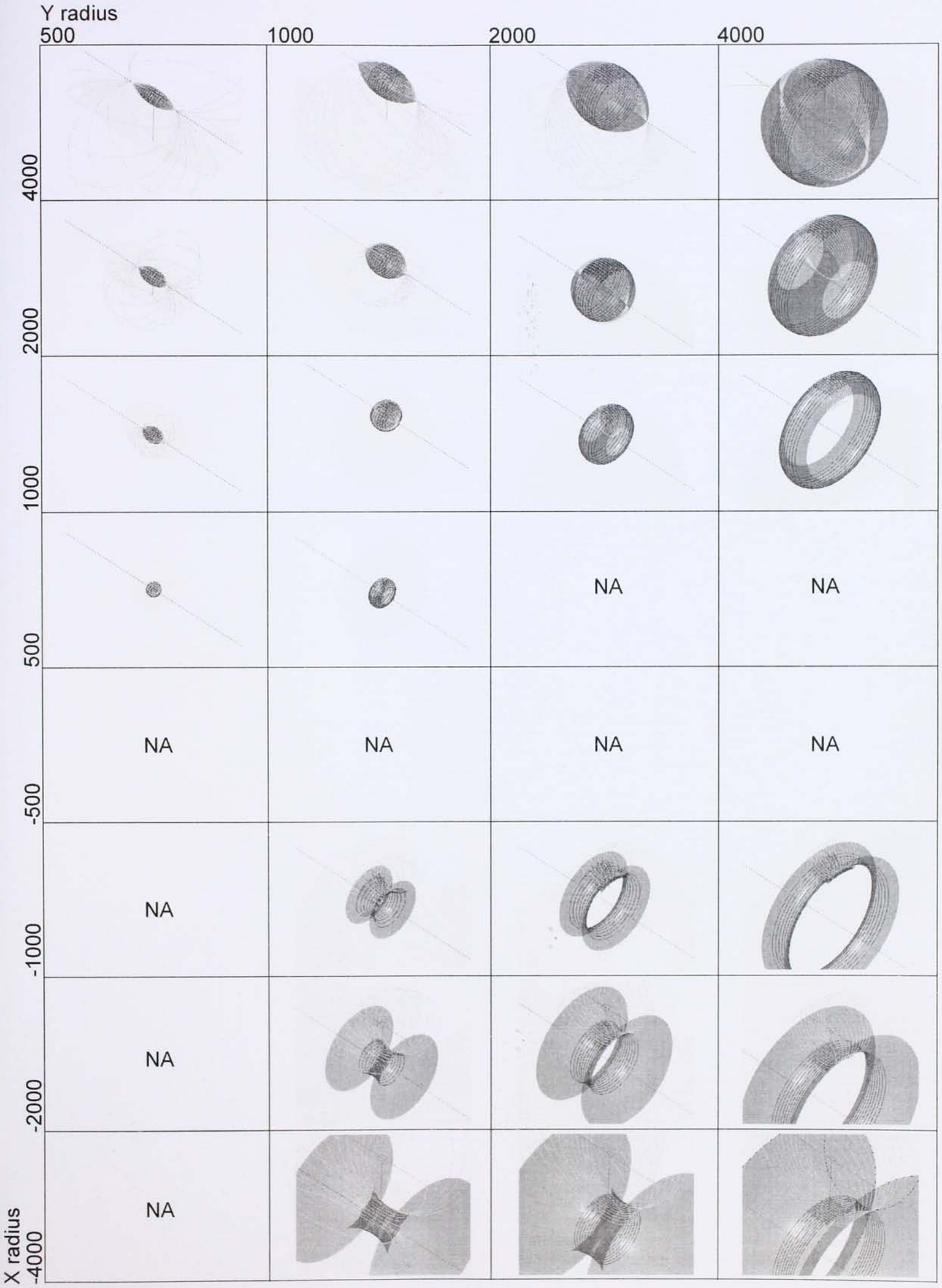


Concave

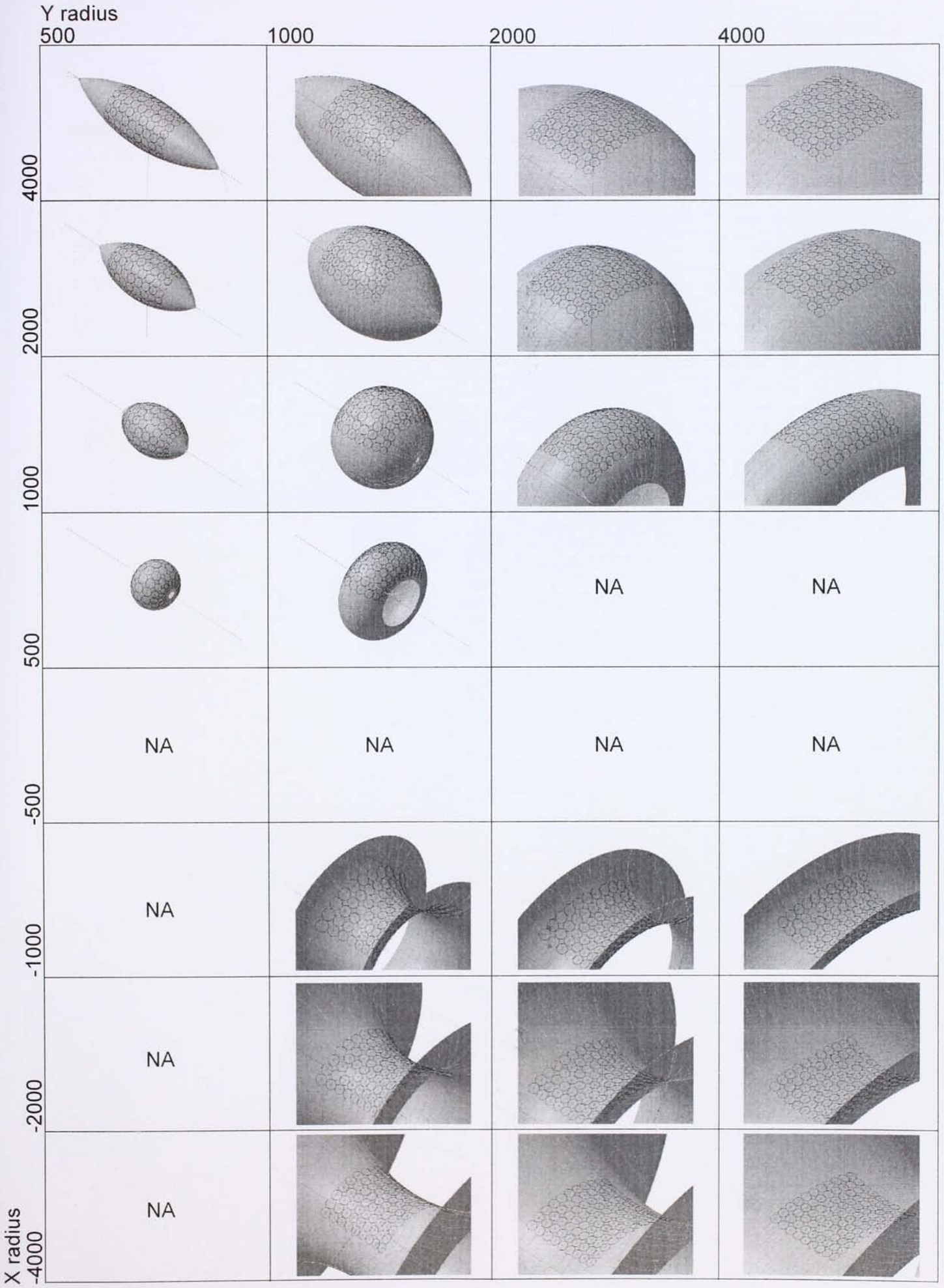




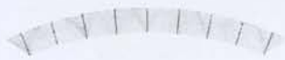
Grid: Isometric view



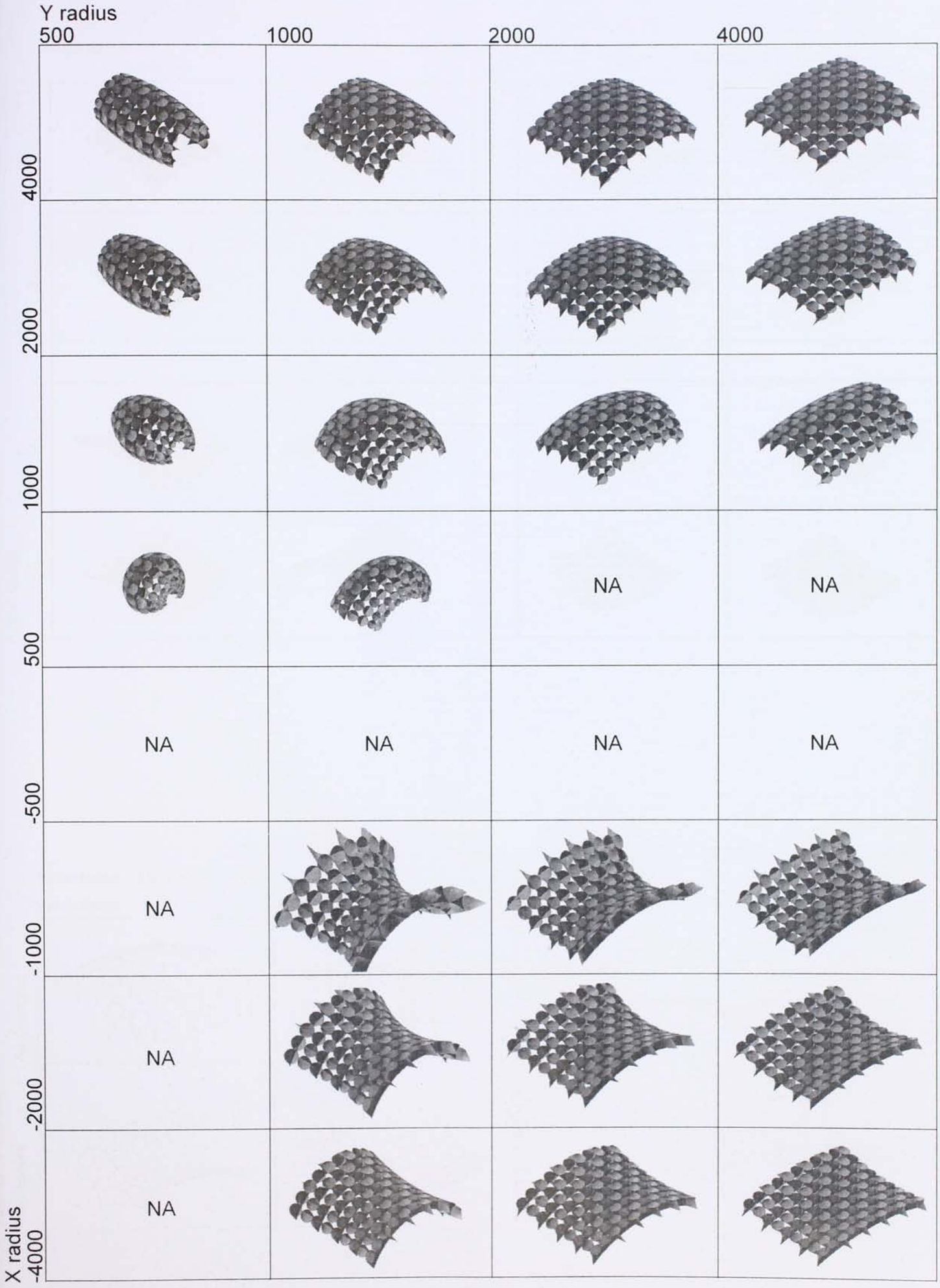
Rings and centre points

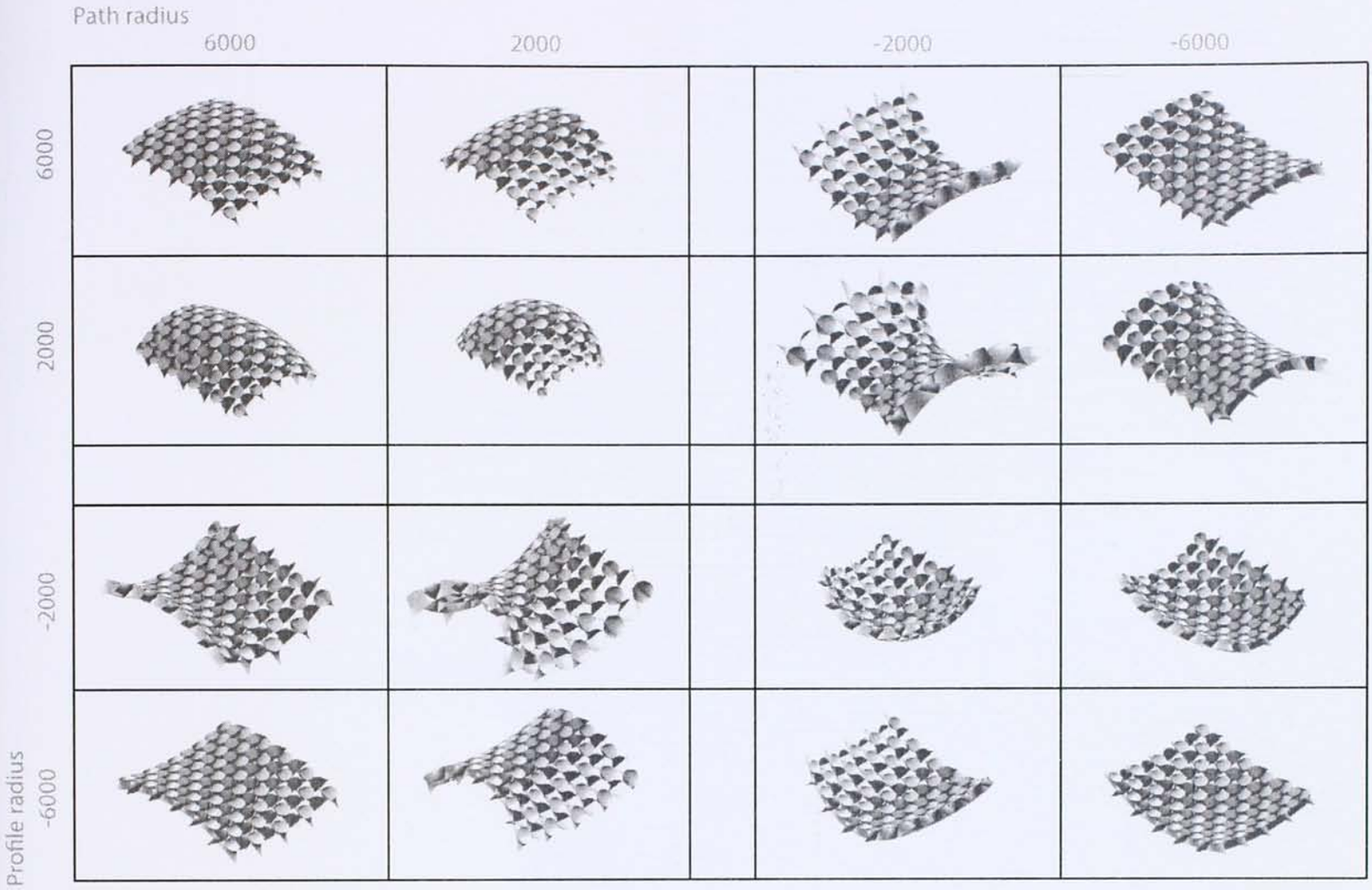


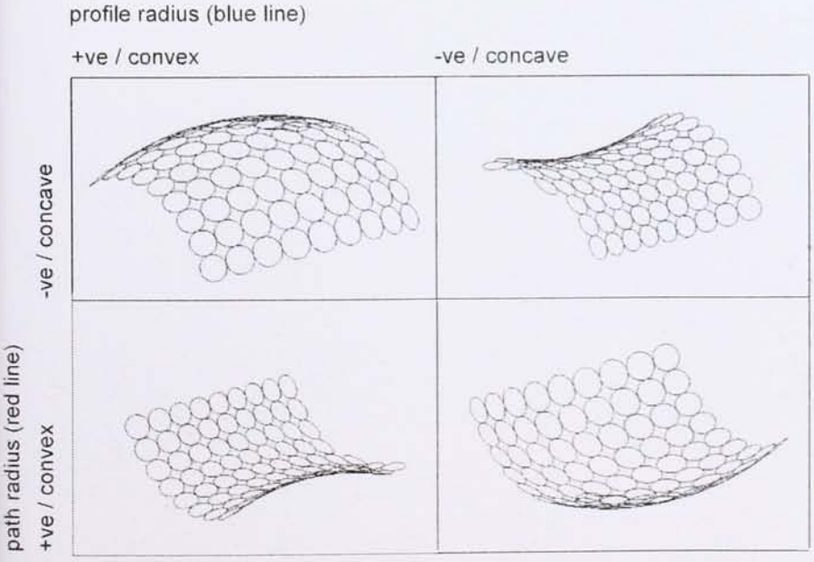
Central lines

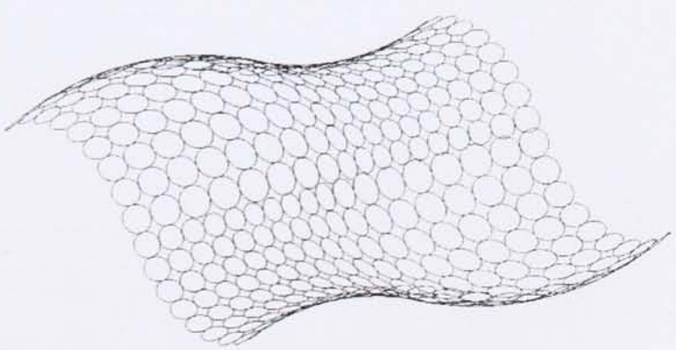
X radius \ Y radius	500	1000	2000	4000
4000				
2000				
1000				
500			NA	NA
-500	NA	NA	NA	NA
-1000	NA			
-2000	NA			
-4000	NA			

Surfaces


Y radius
500
1000
2000
4000
X radius
4000
2000
1000
500
-500
-1000
-2000
-4000
NA
NA
NA
NA
NA
NA
NA
NA
NA
NA

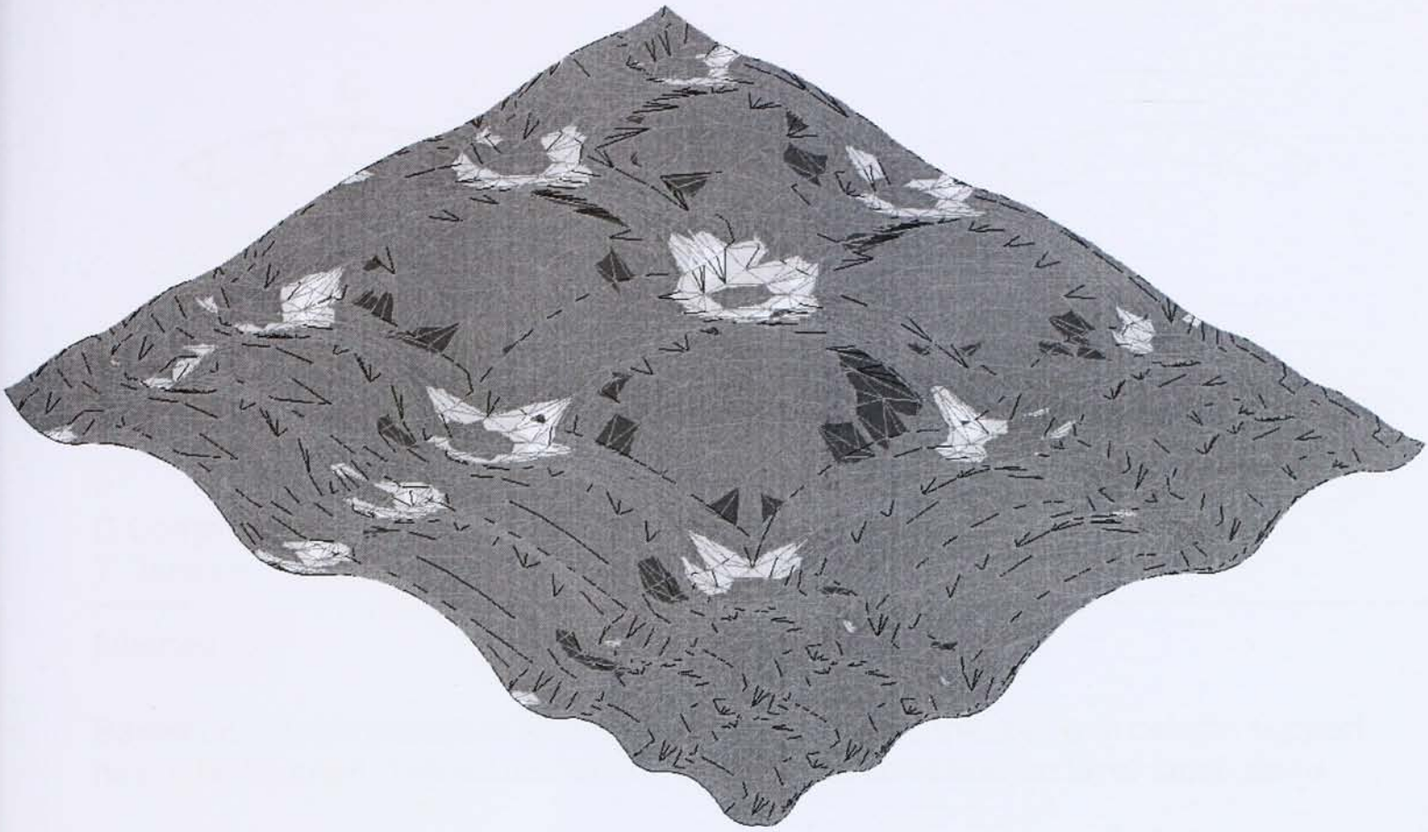

Path radius
6000
2000
-2000
-6000
Profile radius
6000
2000
-2000
-6000

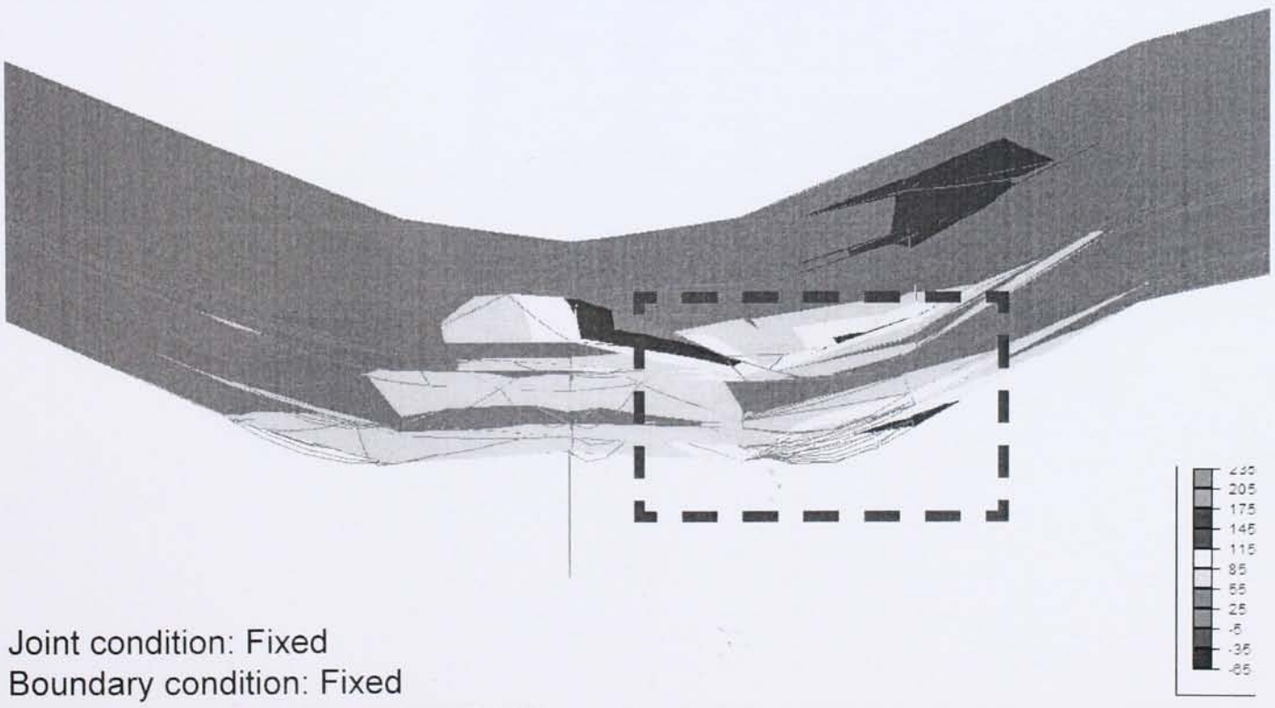

profile radius (blue line)
+ve / convex
-ve / concave
path radius (red line)
-ve / concave
+ve / convex



PART3: STRUCTURAL ANALYSIS AND MODIFICATION

STRUCTURAL PERFORMANCE

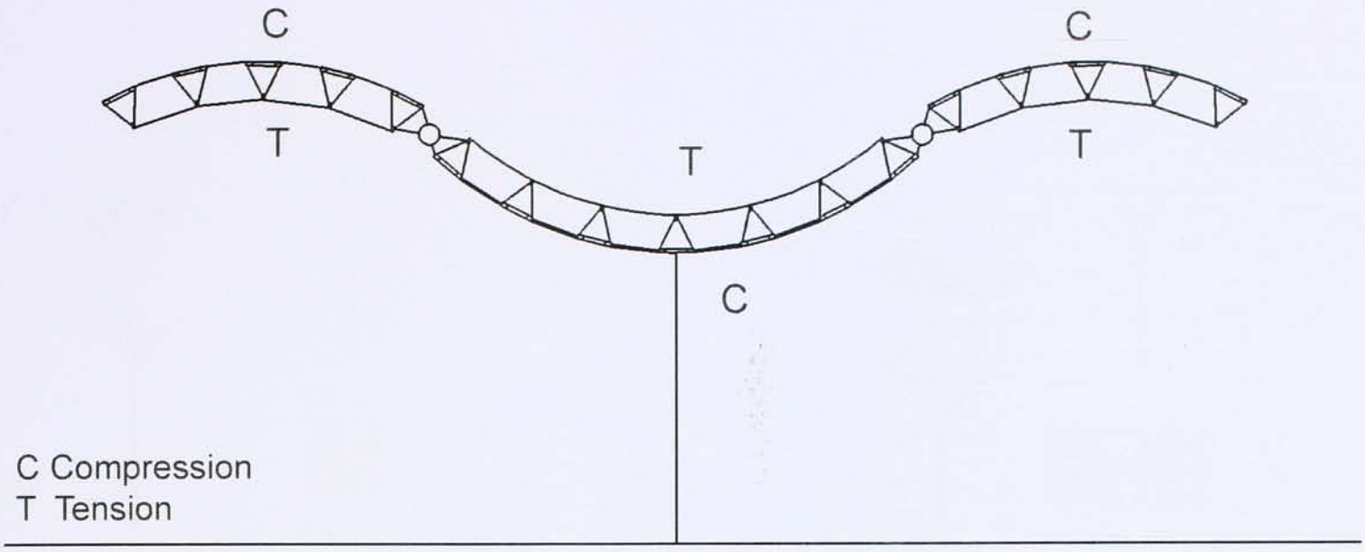




Joint condition: Fixed
Boundary condition: Fixed
Loading: Distributed Loading -5 kN/m

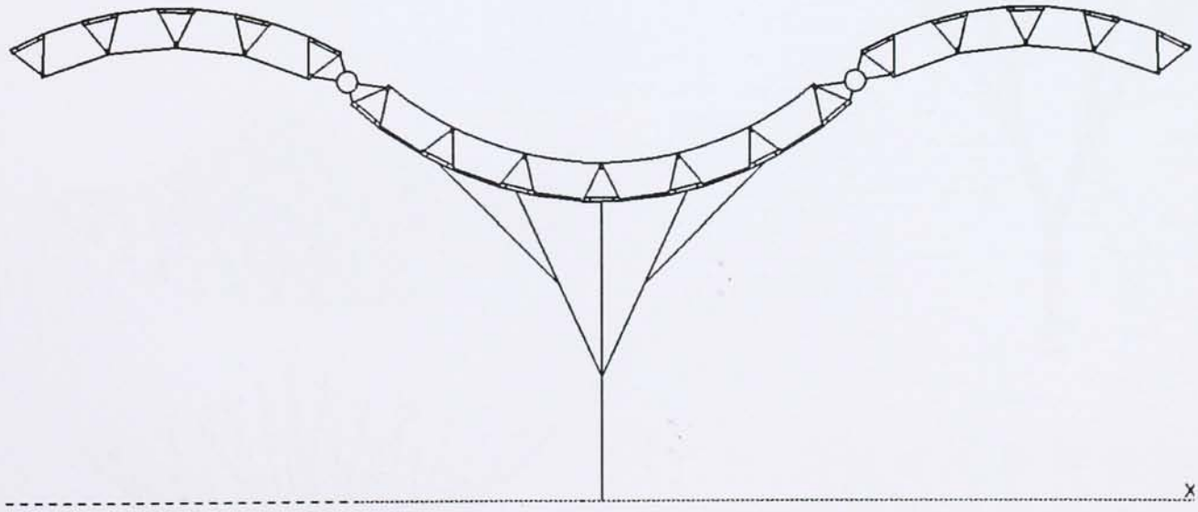
Conclusion: The simulation has shown the stress concentrates at the area near the column sport. Modification of the structure has been explored and shown in the next page.

MODIFICATION OF STRUCTURE



Inverted roof

Based on the compression/ tension principle of a span, the roof with column support has to be inverted. Therefore, the ring which is the compression layer faces down.

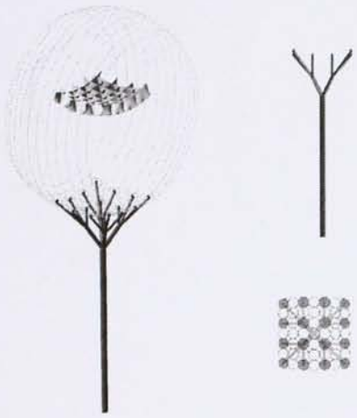


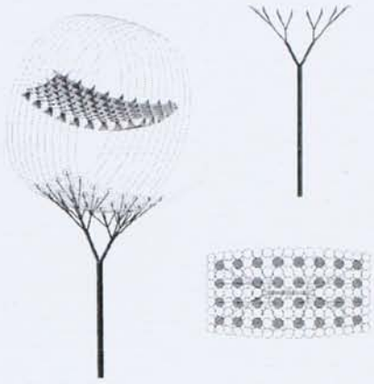
Tree column

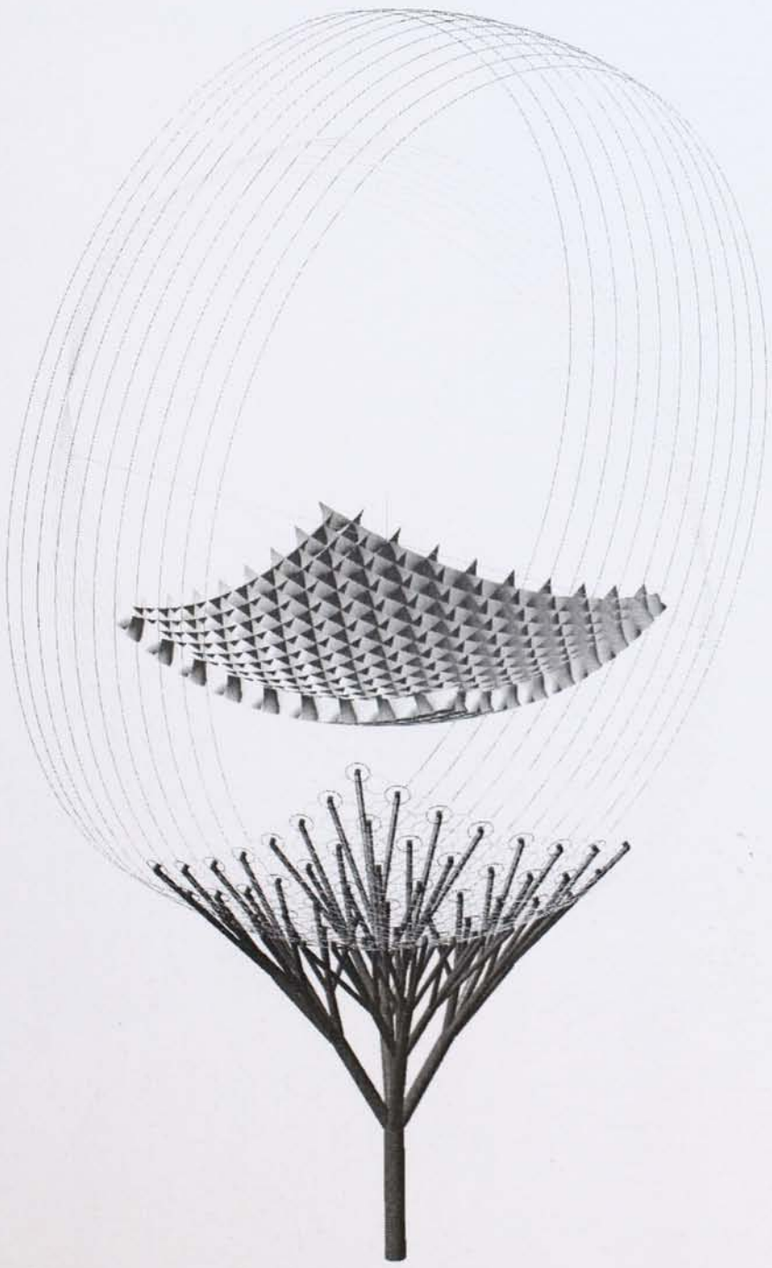
Based on the structural simulation, tree column is used to reduce the deformation of the inverted roof.

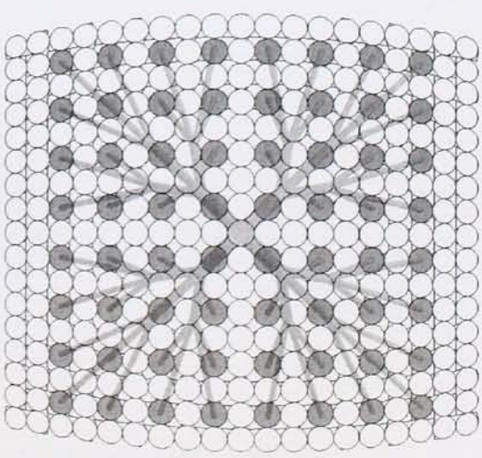
TREE COLUMN

Three types of tree columns are designed for different sizes and proportions of roof. The geometry of columns are depended on the red and blue ring (path and radisu) which defined the curvature of the roof and assembled componets.

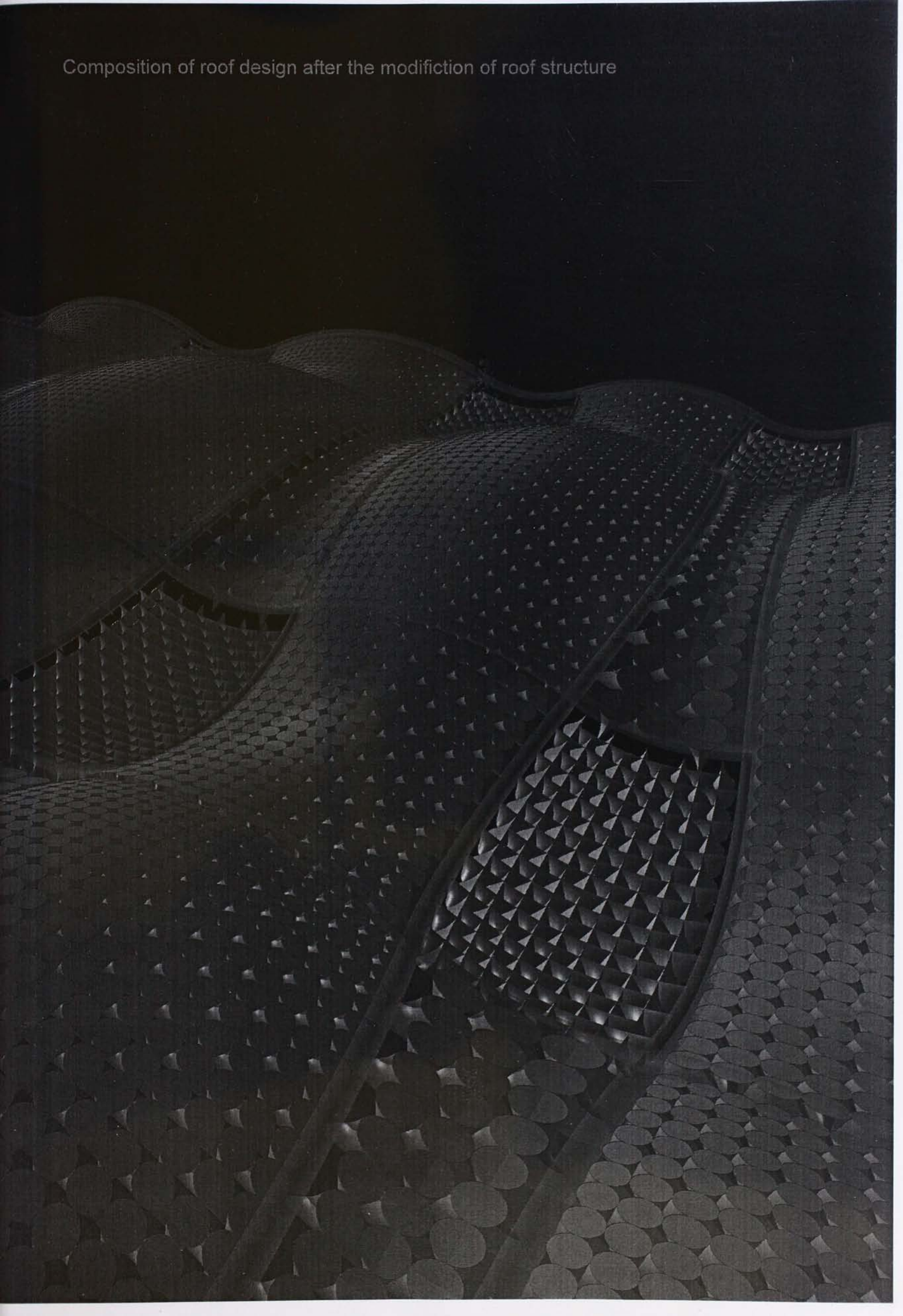








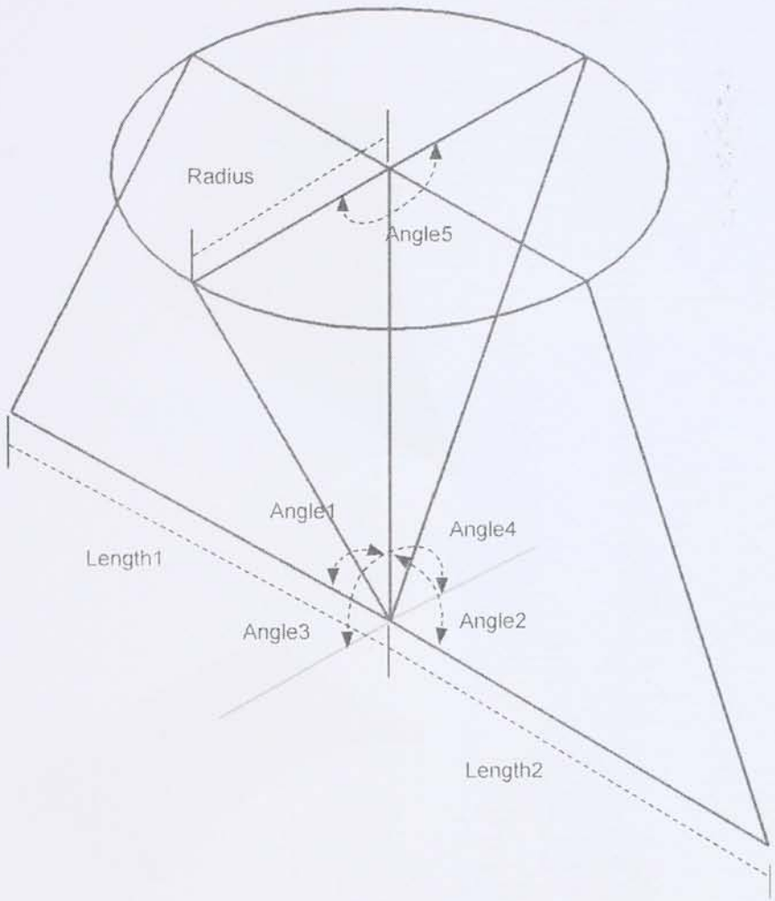
Composition of roof design after the modifiction of roof structure



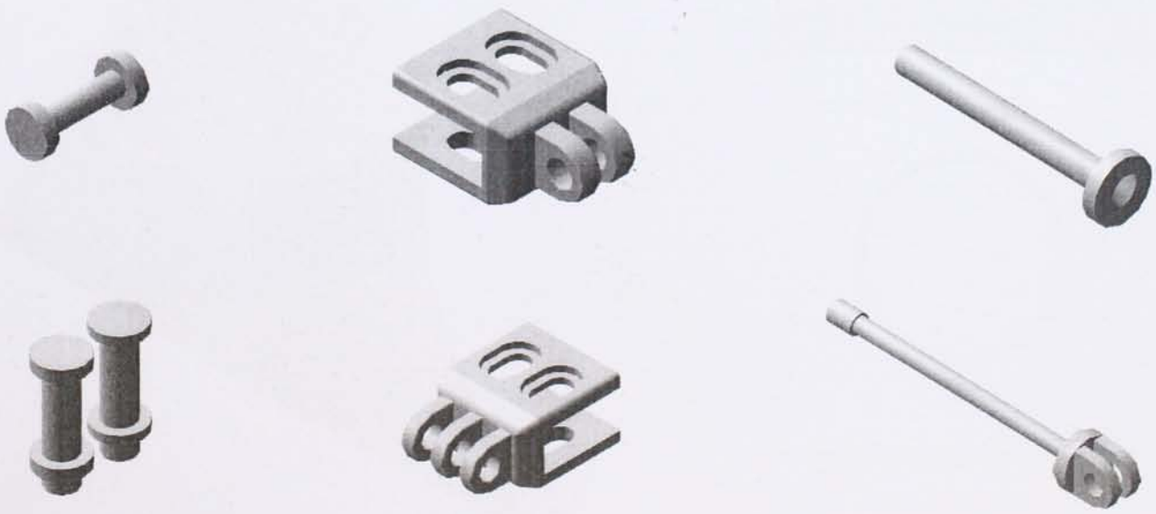
PART4: DETAILING AND FABRICATION

Exploration of parametric variables to understand the behavior of such system and then use this understanding to strategise the system's response to environmental condition and external forces.
Predefined components, mass customization
Digital fabrication to define project specific components
New parametric design technologies and direct fabrication have served to break down the boundary of design and construction. One result is that material experiments in the design studio can be translated directly, with material consistency, to fabrication techniques in the workshop, so that material performances observed and studied at the design stage become integral to the final construction.

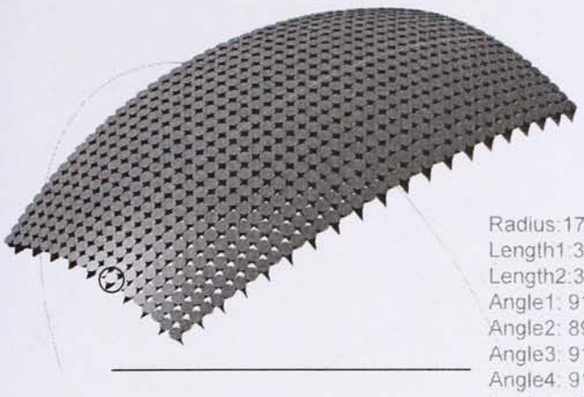
Parameters of module



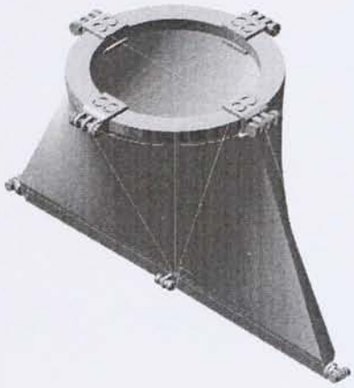
Standardised components for on-site construction

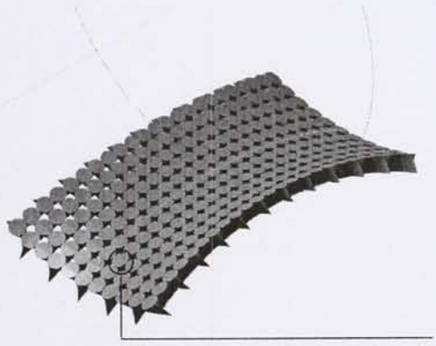


Module granerated with different parameters

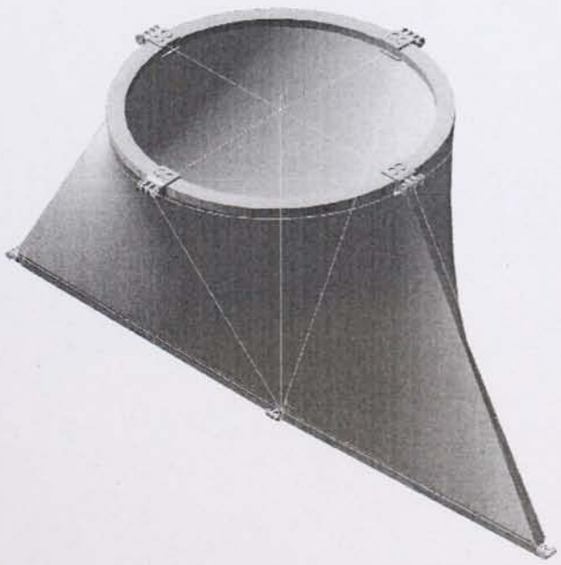


Radius:170mm
Length1:335
Length2:329
Angle1: 91deg41min
Angle2: 89deg29min
Angle3: 91deg12min
Angle4: 91deg12min
Angle5: 178deg56min

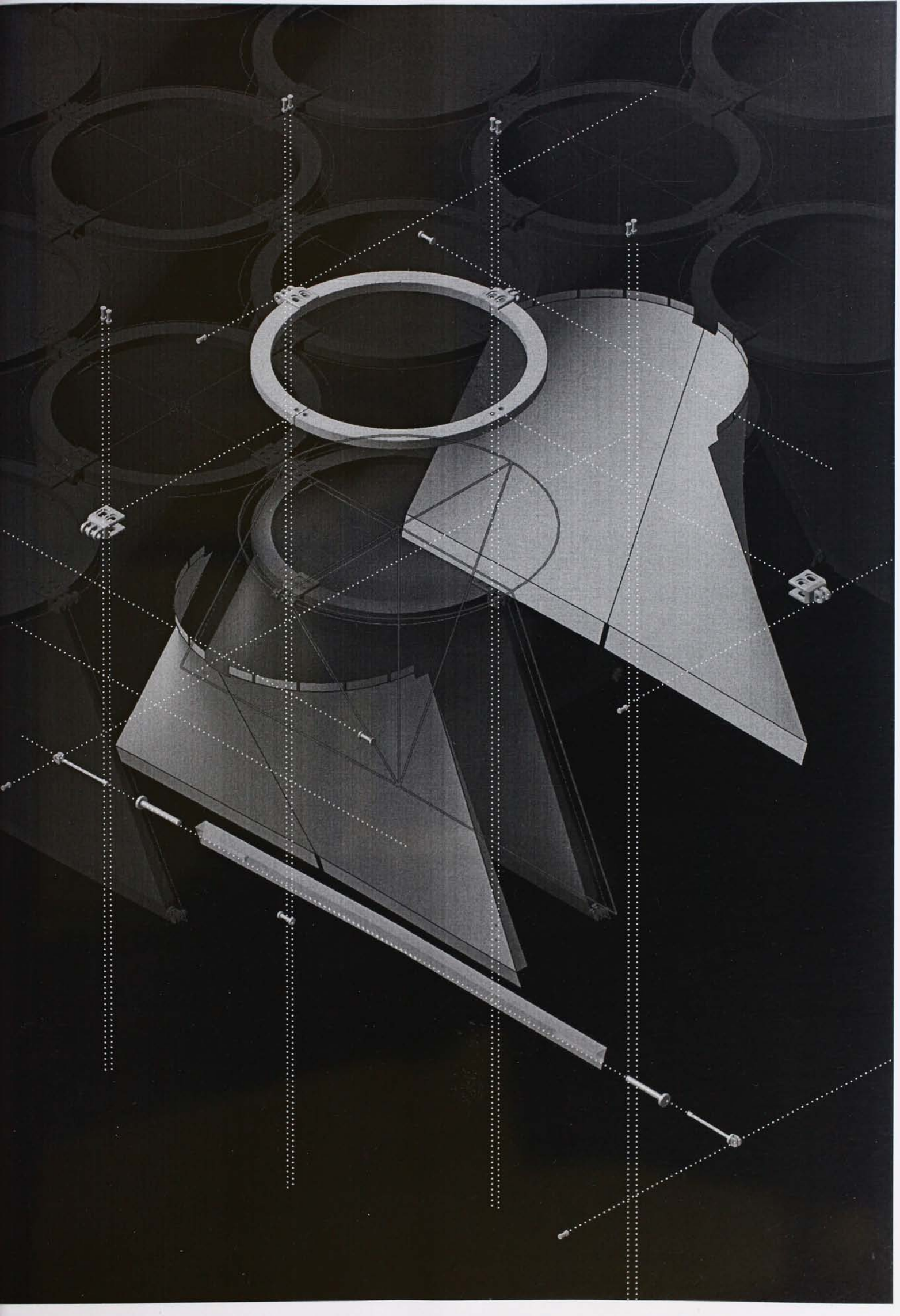


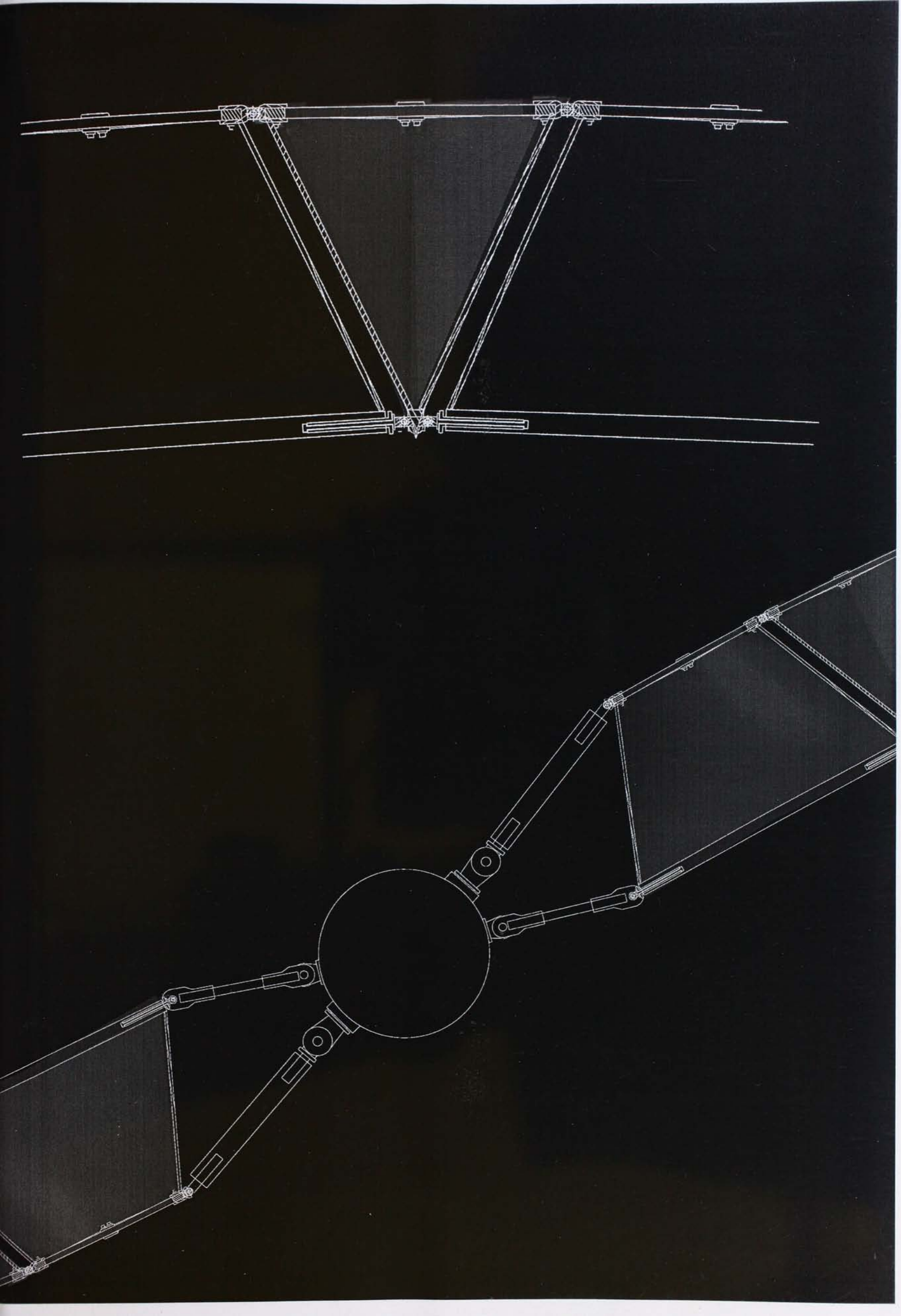


Radius:333mm
Length1:697mm
Length2: 697mm
Angle1: 88deg38min
Angle2: 88deg38min
Angle3: 86deg31min
Angle4: 86deg49min
Angle5: 176deg50min



Components to be fabricated and welded in factory





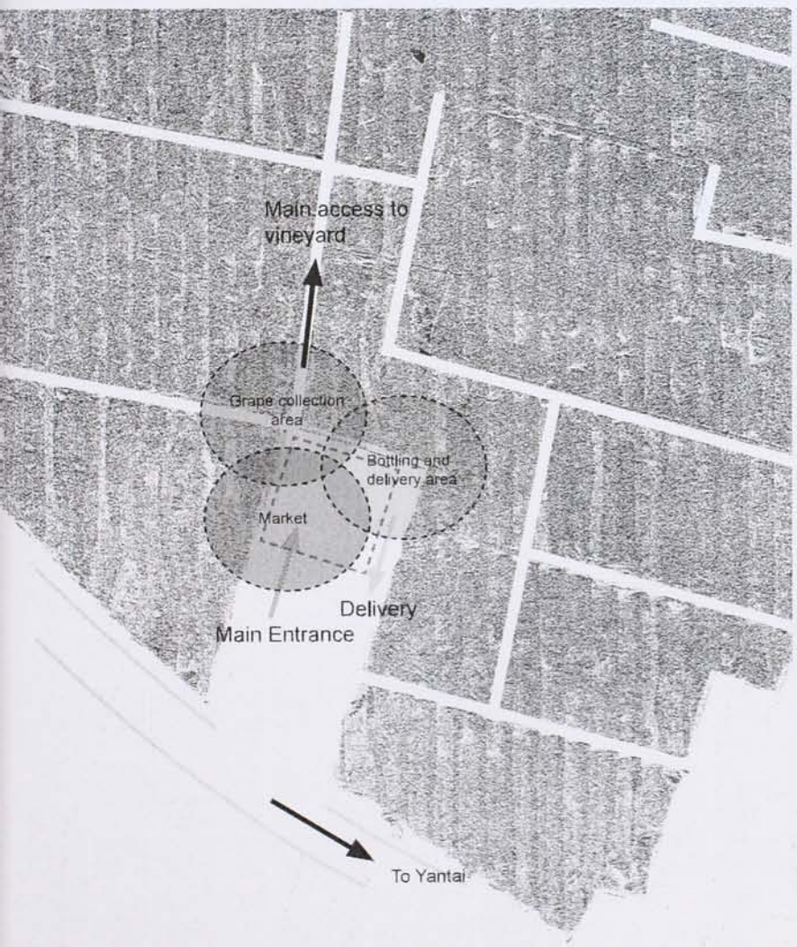
PART5: SPATIAL CONCEPT

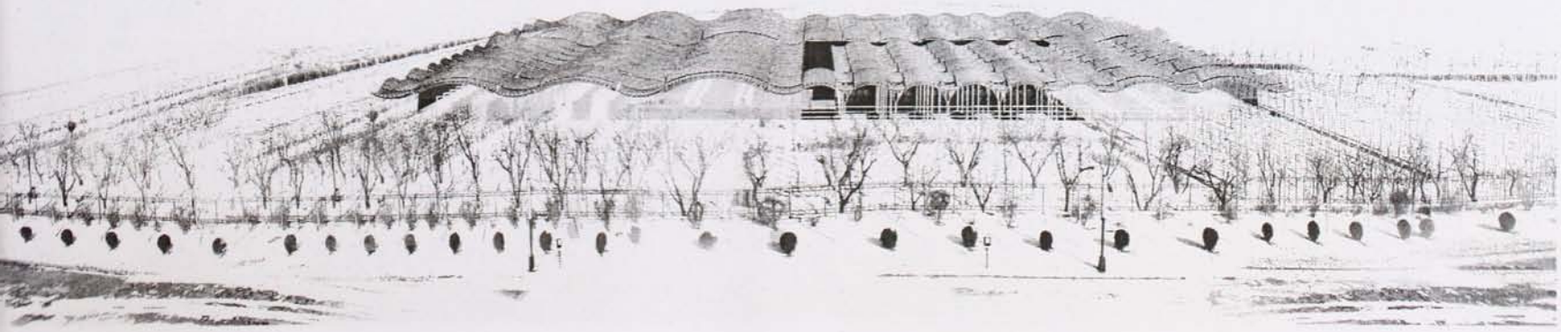
DESIGN PROECT: A WINERY IN YANTAI

SITE INFORMATION

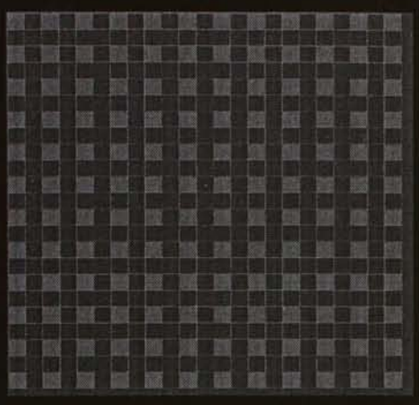
A winery in the western part of Yantai city will be an experimental design to demonstrate the roof design. The site is a flat land surrounded by a large vineyard.

SITE STRATEGY

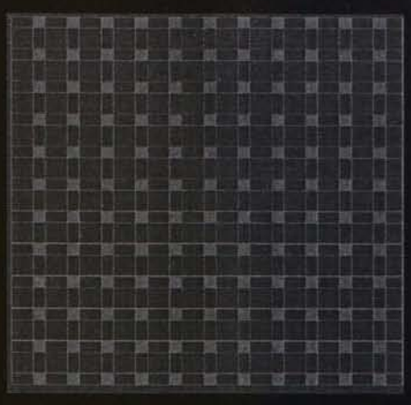




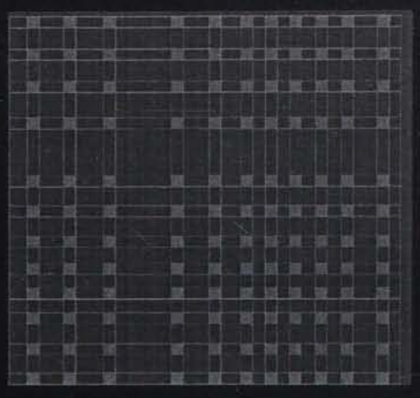
The roof grid is adjusted for different programs. The dimension of the roof with column support is also corresponding to that of the span roof



1) The design start with a orthorgonal grid with equal spacing.

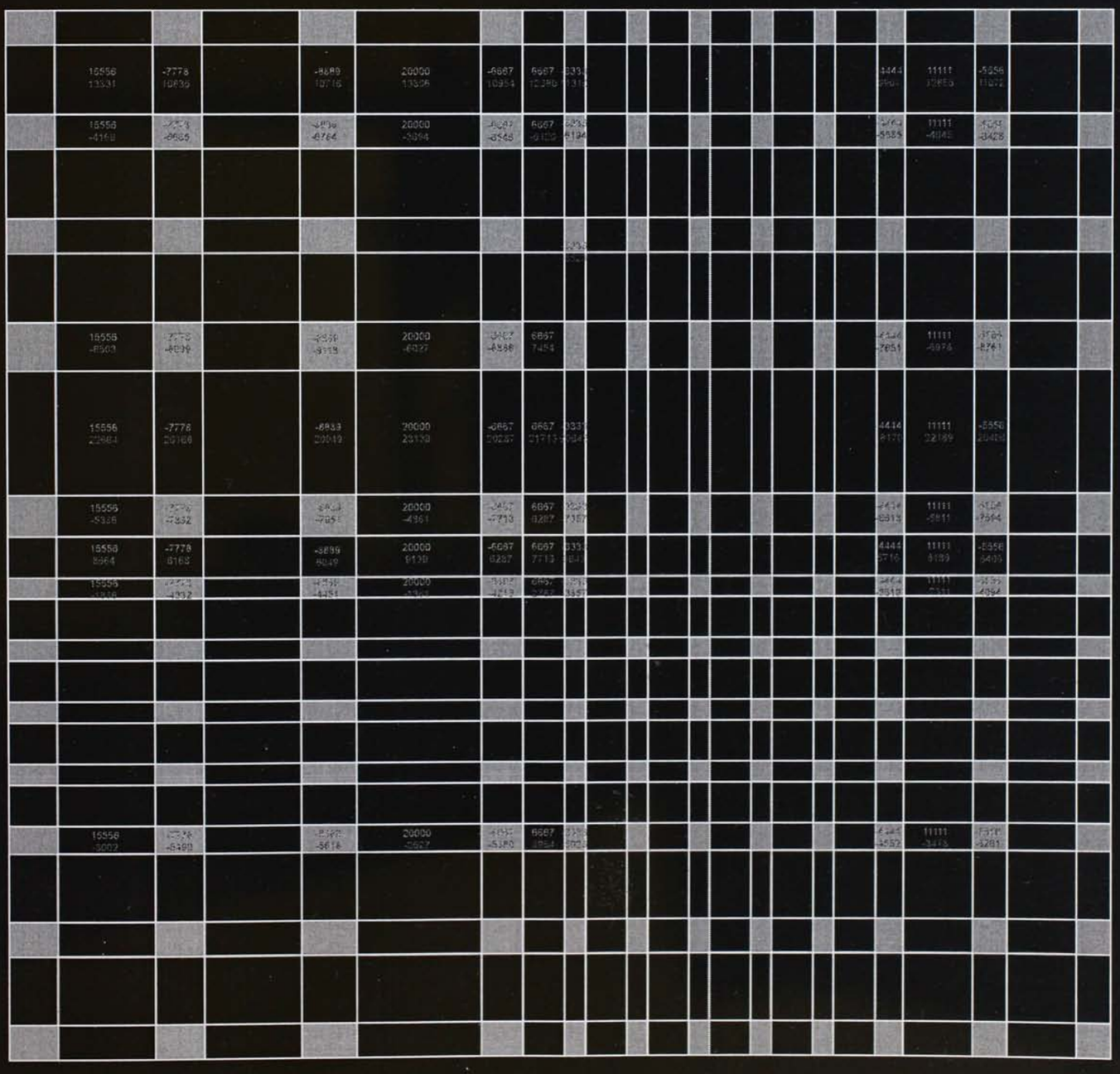


2) The width of 'inverted roof' is reduced in order to provide larger void space

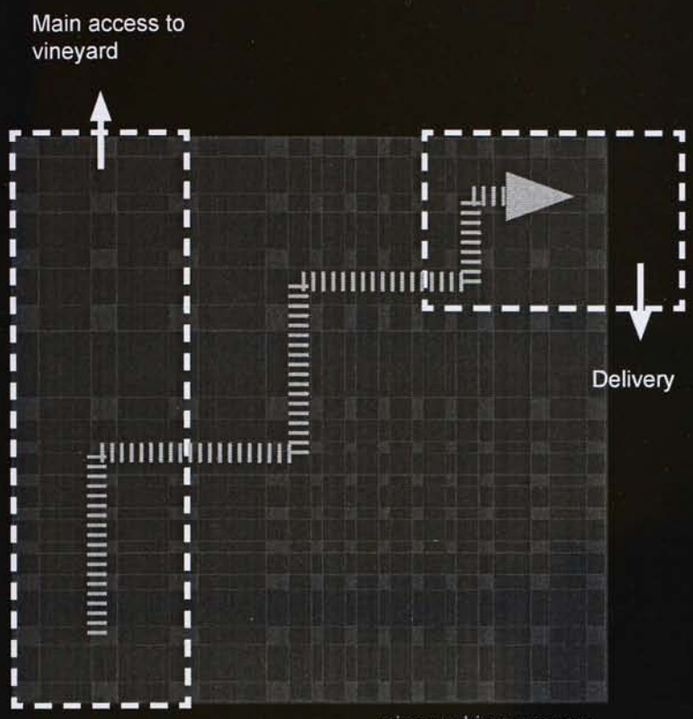


3) The span roof is developed with a variety of spacing for different functions of space.

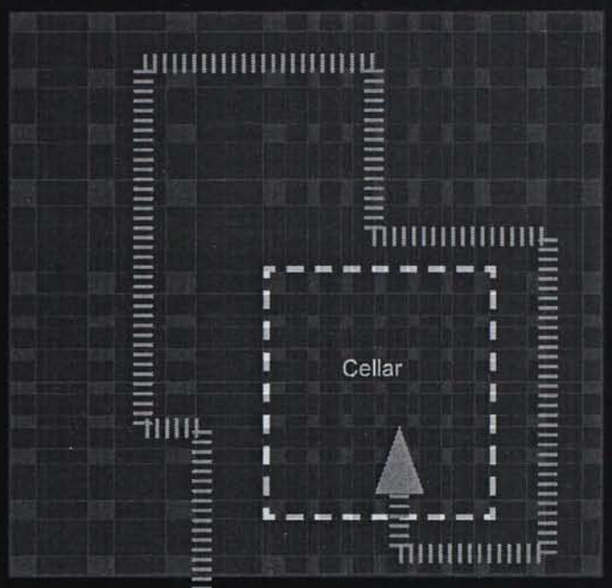
Inverted roof, roof for column support (profile radius -ve, path radius -ve)



4) The width of 'inverted roof' is further adjusted corresponding to the span of the adjacent roof.

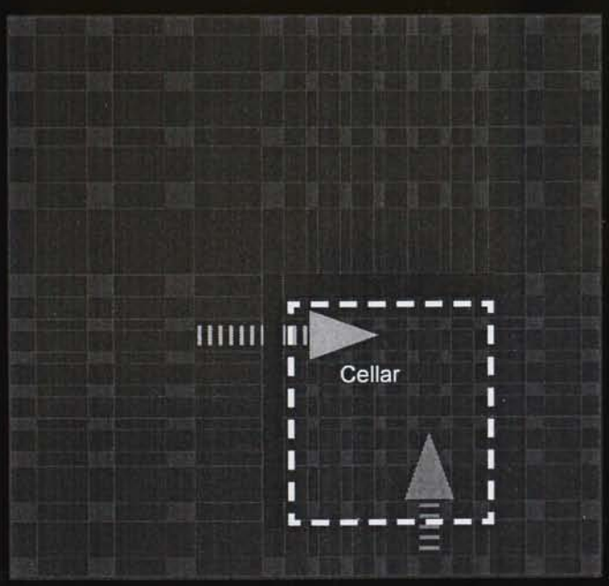


wine making process

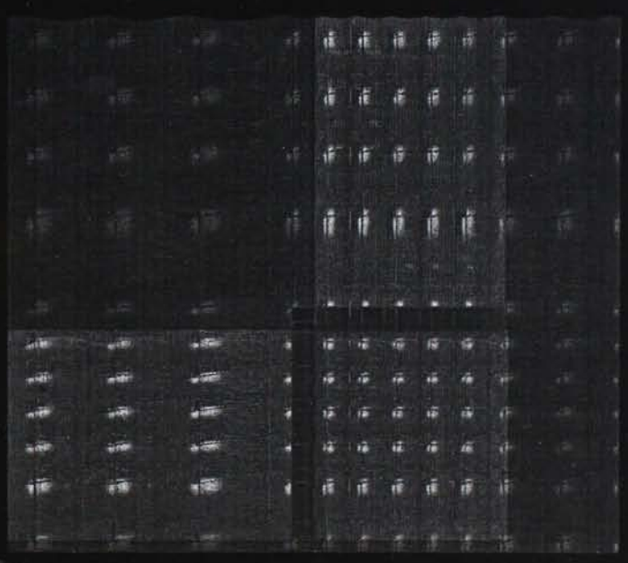


Circulation of visitors

Entrance



Access to rooftop vineyard and cellar



Rooftop vineyard

PROGRAMMATIC ORGANIZATION

Different spaces will be arranged on different levels according to the level of privacy.

Working spaces

wine making process

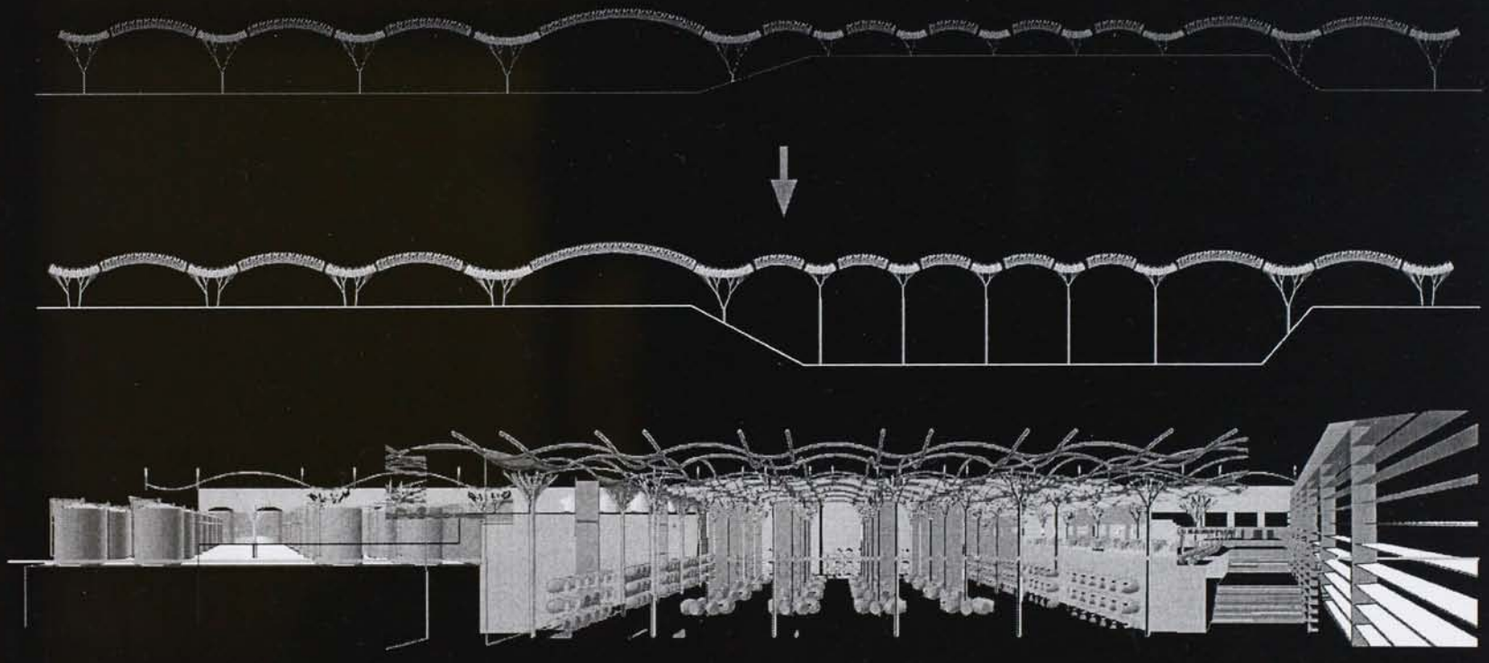
Pressing grape | Fermentation | Wine storgae | Cellar | Bottling

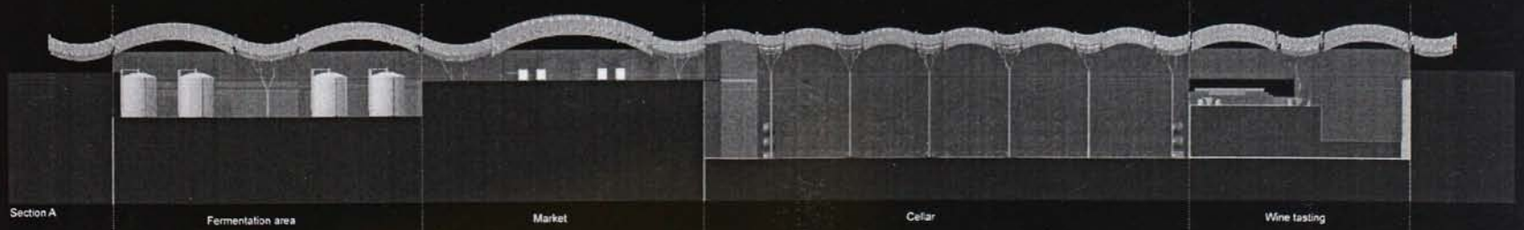
Visitor spaces

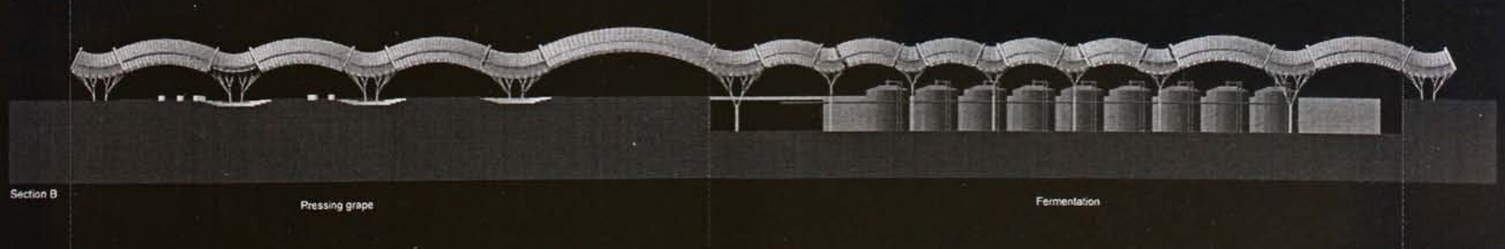
Level of privacy

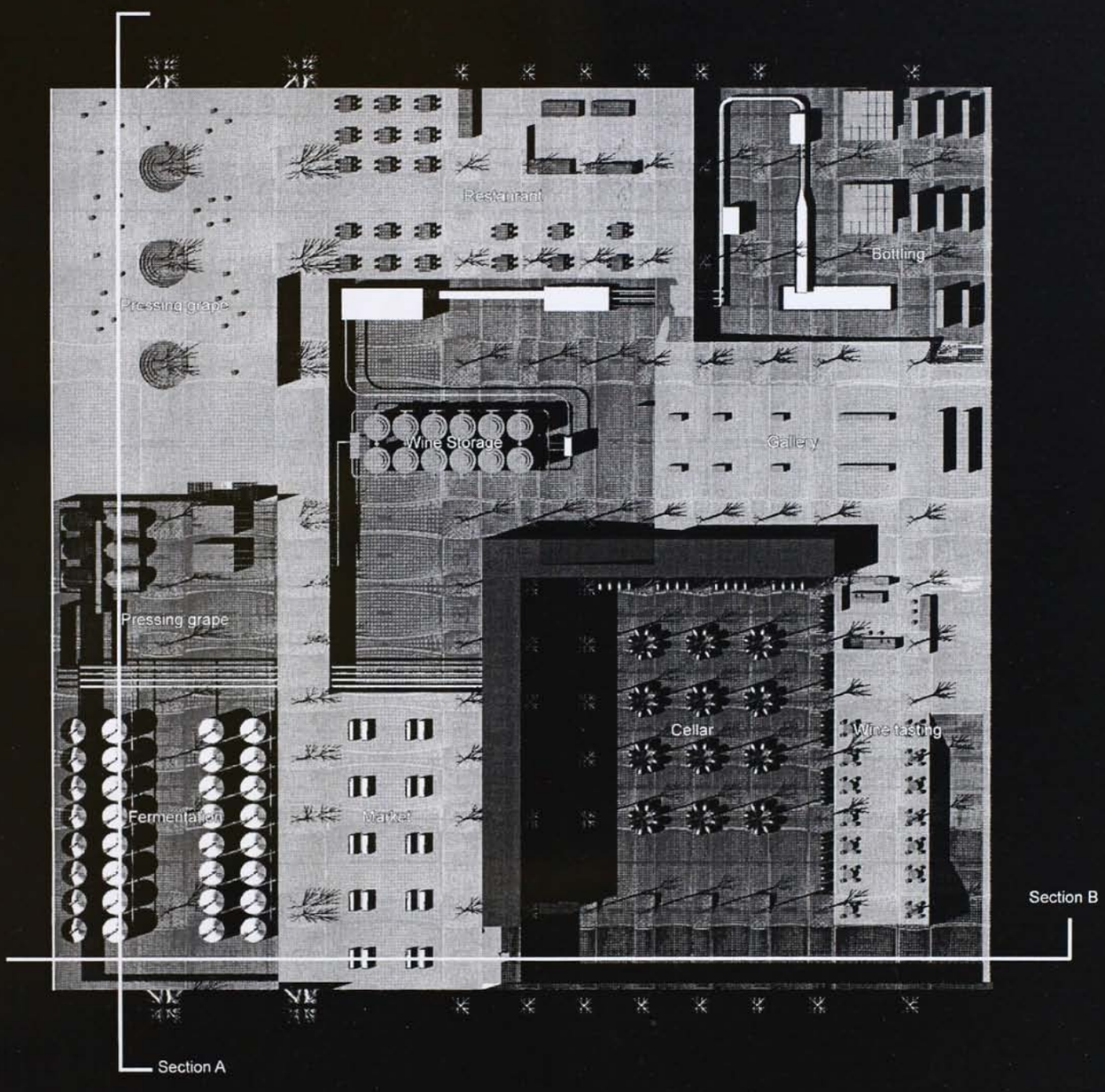
Pressing grape	Market	Restaurant	Gallery	Wine tasting	Cellar
Level: +0	Level: +0	Level: +0	Level: -2000	Level: -3000	Level: -10000

Level change is independent to the size of roof, in order to enhance the spatial variation

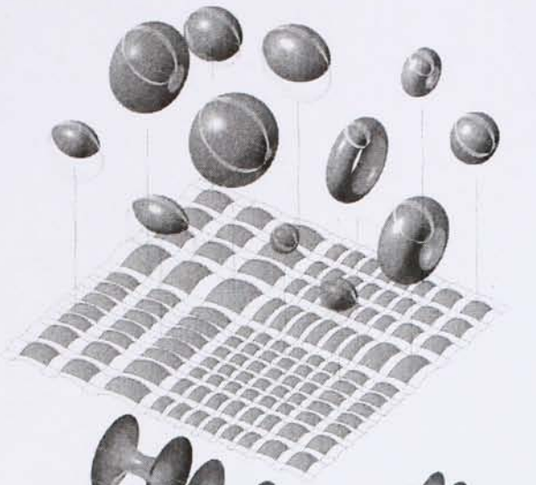




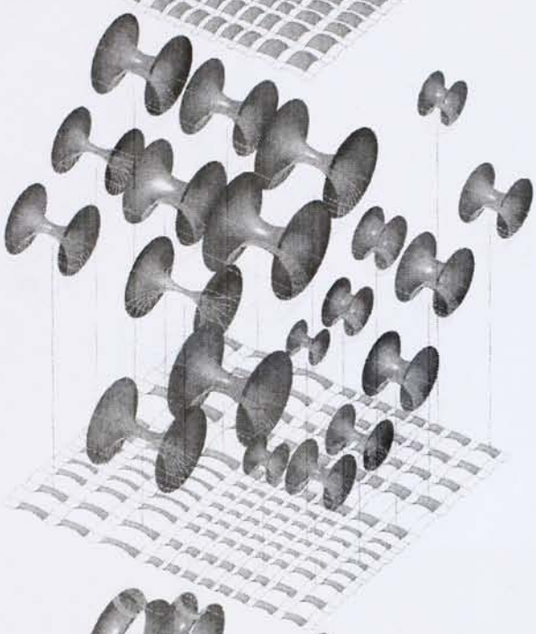



Restaurant
Bottling
Pressing grape
Wine Storage
Gallery
Pressing grape
Cellar
Wine tasting
Fermentation
Market
Section B
Section A

COMPOSITION



Profile radius
Path radius



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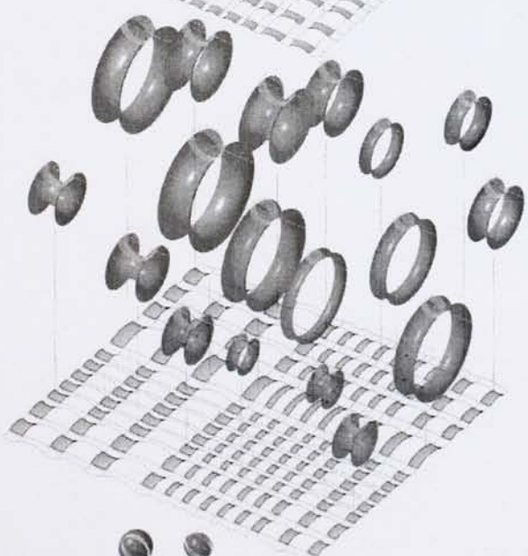

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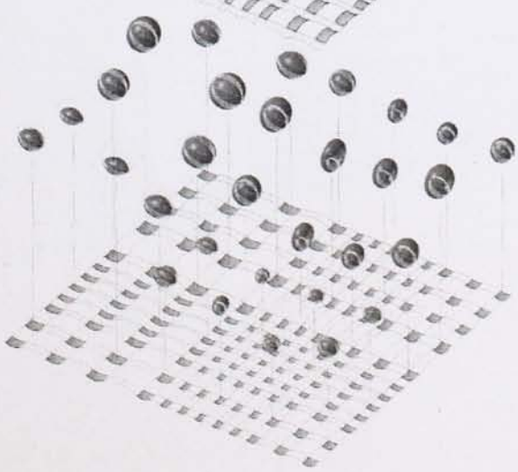

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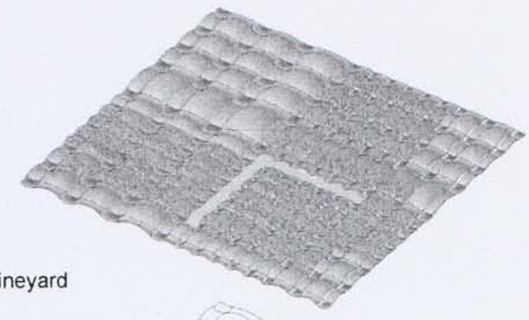
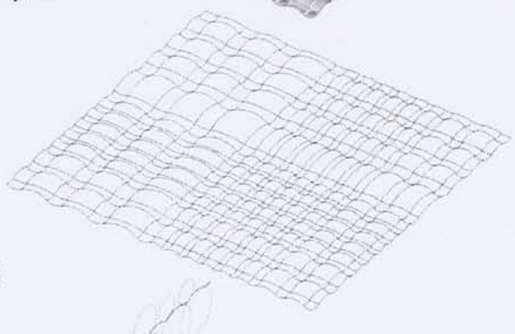


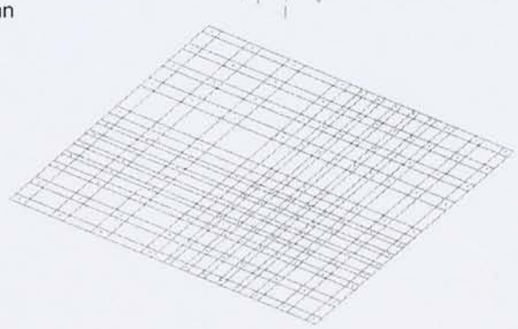
Rooftop vineyard



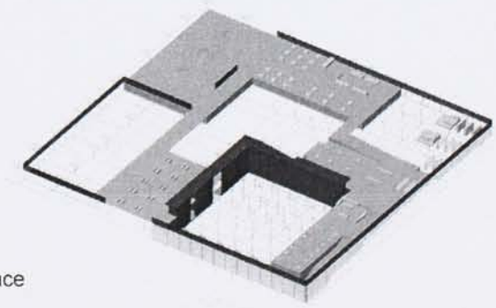
Framework

Curve profile

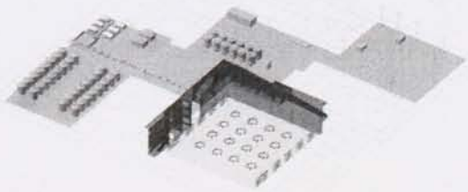
Tree column



Grid



Visitors space



wine making space